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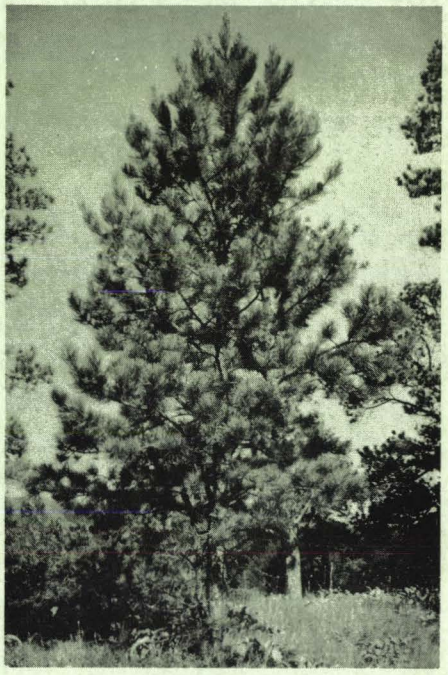
COOPERATIVE EVALUATION OF POTENTIAL AIR POLLUTION INJURY AND DAMAGE TO CONIFEROUS HABITATS ON NATIONAL FOREST LANDS NEAR COLSTRIP, MONTANA

I. Interim Report of Activities

from June 1, 1975---May 30, 1976



USDA - FOREST SERVICE - NORTHERN REGION
State and Private Forestry
AND
UNIVERSITY OF MONTANA
Environmental Studies Laboratory

Missoula, Montana

REPORT NO. 76-12 July, 1976

A COOPERATIVE EVALUATION OF POTENTIAL AIR POLLUTION INJURY AND DAMAGE TO CONIFEROUS HABITATS ON NATIONAL FOREST LANDS NEAR COLSTRIP, MONTANA

I. Interim Report of Activities from June 1, 1975 -- May 30, 1976

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Special appreciation is extended to Charles McGlothlin, District Ranger, Ashland Ranger Station, Custer National Forest, and to others of the Custer Forest staff who aided in various administrative aspects of this study. Similar appreciation is extended to Keith Beartusk, BIA Forester, Northern Cheyenne Indian Reservation, Lame Deer, and to his staff.

Finally, we extend our sincere and special thanks to the Kluver family and to Wally McRae and his family for accommodating us and tolerating our activities for another year. We know our collecting activities do not always occur at times which are convenient for them.

Cover Photos

Upper left -- Electric generating plants at Colstrip, Montana.

Upper right -- Typical healthy ponderosa pine on the Ashland Division, Custer National Forest.

Lower left -- Field technician Donald Berg evaluating growth characteristics of ponderosa pine.

ABSTRACT

Baseline data for the first year of a two-year study to assess the current status of ponderosa pine stands in southeastern Montana relative to coal-fired electric power development are presented. Sixteen permanent plots in pine stands were established in eastern Montana, South Dakota, and Wyoming. Several characteristics believed to be sensitive to future sulfur dioxide and fluoride pollution from the power complex were measured on ten trees from each site. Average fluoride concentration in foliage was 1.48 parts per million (ppm), and total sulfur was 483 ppm. Total chlorophyll was .657 mg/gm (fresh wt.) in current needles, .930 mg/gm in year-old needles, 1.016 mg/gm in 2-year old needles, and 1.016 mg/gm in 3-year old foliage. Average foliar water content was 48.9 percent, and mean needle length was 125.3 mm. Needle retention varied between 97-84 percent, depending on internode age. Average fascicular cross-sectional area was 2.1 sq. mm. A number of different insects, fungi, and abiotic factors contributed to slight yellowing and browning of needles, including elegans pine weevil, basal side, various defoliators, and weather factors. Average total necrosis (tissue death) due to the sum of all these factors was less than 7 percent. Measurements of airborne reactive sulfur and fluoride by static plate techniques were negative. This, combined with the very low foliar concentration of sulfur and fluoride, establish the study area as virtually pollution free as of 1975. Additionally, comparisons between the

baseline study area and known polluted sites throughout the United States indicate that the polluted sites differ significantly in regard to then pine characteristics measured, and that the degraded pine conditions in the polluted areas are due to airborne sulfur and fluoride concentrations similar to those expected in the near future from the Colstrip power generating facilities. It is anticipated that the ponderosa pine in the study area will be affected. This baseline study will be a convenient, if not necessary, document with which to compare future data in order to detect pollution insults on the pine forests in southeastern Montana.

INTRODUCTION

Intensive development of the sub-bituminous coal resource in the Fort Union Basin, including portions of eastern Montana, northern Wyoming, western South Dakota, and western North Dakota, is now in progress. That development may soon become extensive. The complexity of interacting consequences of this development is enormous, but through some 533 different studies[1], an attempt is being made to elucidate some of the expected social, economic, and biological impacts of coal activities. Mine-mouth, coal-fired thermal electric generating plants are one faction of the coal development panorama. Besides generation of useful energy in the form of electricity, a myriad of pollutants are expelled to the airshed via tall ($\geq$ 500 feet) smoke stacks. Many of these pollutants, including sulfur oxides (SO_x), nitrogen oxides (NO_x), and fluorides (F^-), which are primarily gaseous, and heavy metal particulates, including mercury, cadmium, zinc, and others, are biologically active and are capable of causing injury and damage to living ecosystems.

Two 350-megawatt plants have been completed at Colstrip, Montana, and two more units, each of 700-megawatt generating capacity, were recently given siting approval by the State of Montana Board of Natural Resources. It has been estimated

1. Energy Research Information System, Old West Commission, and USDA, SEAM.

(Tsao and Wicks, 1974) that 58,000 tons of sulfur dioxide (SO_2), 56,000 tons of nitrogen oxides (NO_x), 19 tons of fluoride (F^-), and 5000 tons of particulate will be injected to the atmosphere each year from this four-unit complex. It is expected that the pollutants will be transported by air to local and distant ecosystems, and that varying amounts of damage will result.

Public lands administered by the Custer National Forest, USDA Forest Service, are located 24 miles from Colstrip at their nearest point, directly downwind (southeast) of the generating facilities. This study was conceived and implemented in 1975 in consideration of the facts that:

1. Biologically active pollutants will be emitted from the power plants;
2. Further development of the coal resource and expansion of energy conversion facilities is expected;
3. National Forest, Indian, state, and private lands supporting pure stands of healthy ponderosa pine are located in the expected plume path, and that ponderosa pine is very susceptible to SO_2 and F^-;
4. The pines are an economically important resource in the Fort Union Basin, and because of their sensitivity to SO_2, are a good indicator species of pollution impact;
5. Studies by others have not included the pine resource of the Ashland Division, Custer National Forest.

The purpose of this investigation was to characterize and measure, prior to power plant operation, pertinent biological and physical parameters of the ponderosa pine ecosystem on the Ashland

Division, Custer National Forest. This study is designed as a pre-operational detection survey and is necessarily concerned with those biological attributes that will signal an early warning to an air pollution problem. It is not designed to measure economic impact on the ponderosa pine resource. Because of related existing studies centered primarily outside the Custer Forest by the Environmental Studies Laboratory (EVST), University of Montana, it was decided to pool the resources of EVST and the Forest Service within the legal framework of a cooperative agreement in order to efficiently expedite this endeavor. Financing was accomplished by a transfer of funds from SEAM to the Forest Service, Region I, and monies were allocated to the University and Forest Service Air Pollution Group via Cooperative Agreement Number 01-013. A broad outline of study design was presented (Carlson and Gordon, 1975), which was modified for financial reasons to the design presented in the following section.

MATERIALS AND METHODS

Sixteen permanent sites were established in pure ponderosa pine stands in the Fort Union Basin (Figure 1, Table 1). Ten sites were selected on the Ashland and Fort Howes Ranger Districts, Custer National Forest, inclusive, one in the Northern Cheyenne Reservation, two on private lands near Colstrip, one in the Bearlodge Mountains of northeastern Wyoming, and two in the Black Hills of South Dakota. Each site selected for future study had to meet the following criteria:

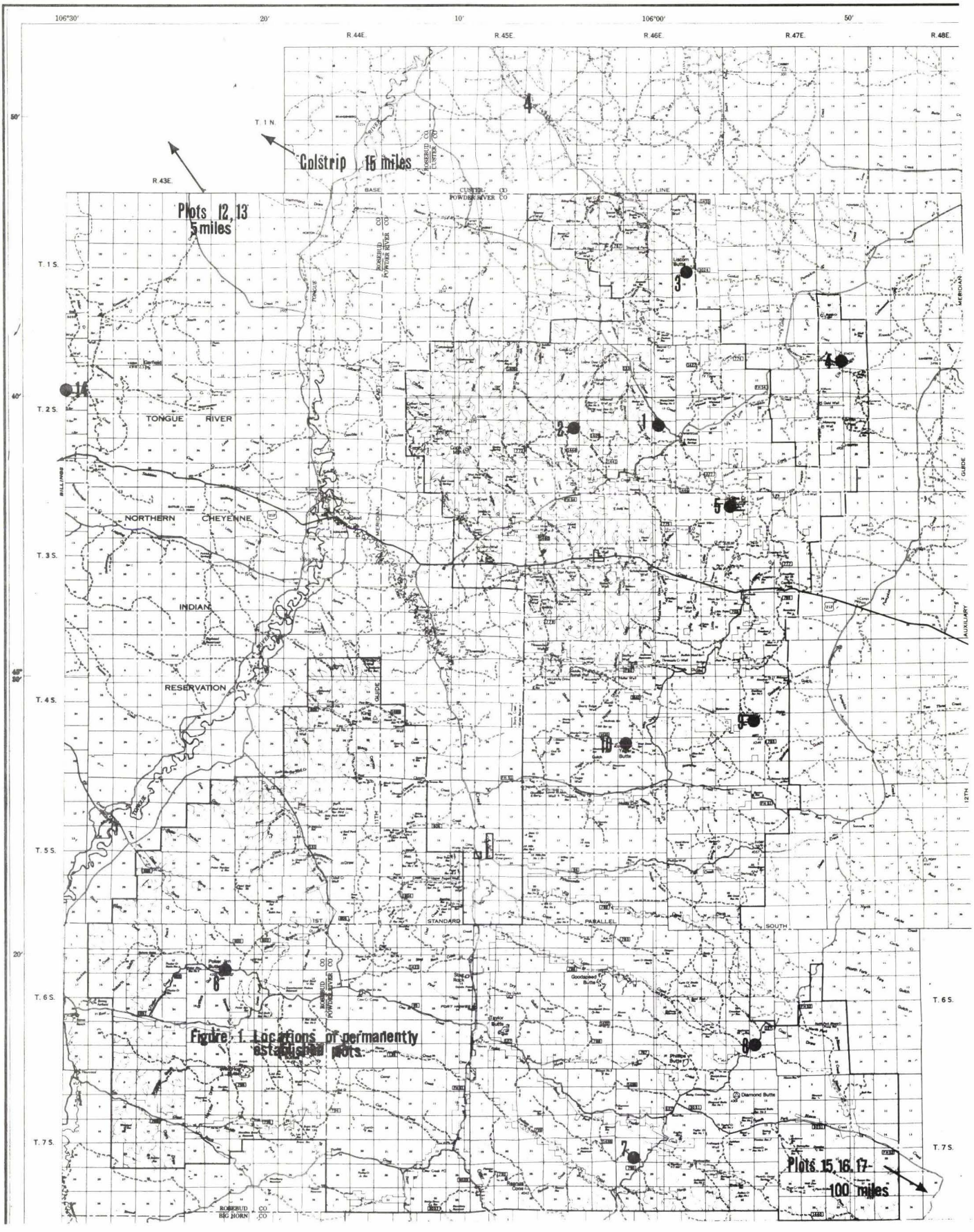


Figure 1. Locations of permanently established plots.

TABLE 1

DESCRIPTIVE DATA OF PLOT LOCATIONS

Plot #	Name	State[1]	County	Township	Range	Section	Distance and Direction from Colstrip[2]	Collection Date
1	Whitetail Guard Station	M	Powder River	2S	47E	NW 19	34 ESE	6-27-75
2	Beaver Creek Divide	M	" "	2S	46E	SW 21	31 SE	7-09-75
3	Liscom Butte	M	" "	1S	47E	SE 18	32 ESE	7-16-75
4	Buckberry Creek	M	" "	2S	48E	SE 6	39 ESE	7-29-75
5	Home Creek Butte	M	" "	3S	47E	NW 4	37 ESE	7-29-75
6	Poker Jim Butte	M	Rosebud	6S	44E	SE 8	40 SSE	10-17-75
7	Indian Creek	M	Powder River	7S	47E	SW 19	54 SSE	11-05-75
8	Lyon Creek	M	" "	6S	47E	SE 35	53 SE	11-04-75
9	Three Mile Buttes	M	" "	4S	47E	NW 22	43 SE	9-09-75
10	Yager Butte	M	" "	4S	46E	NW 26	40 SE	9-11-75
12	Kluver Family Ranch	M	Rosebud	2N	42E	SW 29	3 E	8-12-75
13	McRae Ranch	M	"	1S	42E	SW 1	10 SSE	8-06-75
14	Morningstar Viewpoint[3]	M	"	2S	41E	NE 12	16 SSE	9-07-75
15	Terry Peak	SD	Lawrence	50N	2E	NE 11	190 SE	8-20-75
16	Bearlodge	W	Crook	64N	---	NW 16	150 SE	8-21-75
17	Crows Nest	SD	Pennington	47N	1E	SW 12	190 SE	9-23-75

1. M = Montana, SD = South Dakota, W = Wyoming
2. 34 ESE = 34 miles east-southeast
3. Northern Cheyenne Indian Reservation

a. should be the most elevated site in the immediate area, and,

b. should be composed of different aged ponderosa pine and have a diversity of understory species.

Only the Terry Peak site in South Dakota could be considered a polluted site because of its proximity to a gold smelter at Lead, South Dakota. Even so, Terry Peak is upwind of the smelter, and our site was selected on the aspect facing away from the smelter (towards Colstrip), and it is improbable that significant quantities of pollutants from the smelter reach that site.

Ten ponderosa pines (see Appendix V for a list of scientific and common names of all plant species collected) were selected and permanently marked for future reference by attaching a metal tag in a shallow blaze at the base. Five of the trees were arbitrarily selected as "old" and five as "young" based on height, diameter, aspect, position on slope, and relative dominance.

Four branches were removed from each of two crown positions, upper and lower, facing Colstrip. For chlorophyll measurements, five fascicles were immediately removed from each of five internodes (1975, 1974, 1973, 1972, 1971) from each of the four branches. Fascicles of similar age and crown position were combined, placed in a plastic bag, labeled, and deposited in an ice chest.

The collected branches were placed in large plastic bags, labeled, and transported either to our field laboratory at Whitetail Administrative Site, the Forest Service Forest

Environmental Protection Laboratory (FEP) at Missoula, or the EVST Laboratory at Missoula. In all cases, the foliage was maintained in as cool a condition as possible.

A variety of understory vegetation was collected from each site, labeled, and transported to the field laboratory. Because the understory varied between sites, it was impossible to collect the same species at all sites.

We determined that the following pine variables would be of interest in our pre-pollution study:

1. Needle retention
2. Needle pathology
3. Needle length
4. Fascicular cross-sectional area
5. Moisture percentage
6. Total sulfur and fluoride content
7. Total chlorophyll.

To quantify these variables, we cut each of the branches from a given tree and crown position into internode segments to separate the foliage by age. Four internodes were selected from each of the four most recent age classes, the number of fascicles retained and cast on each internode was determined, and percent needle retention was recorded. Next, all fascicles were removed and maintained by age (1975, 1974, 1973, 1972). One hundred fascicles of each age were randomly selected, the sheaths removed, and 100 individual needles saved. Each of the 100 needles was carefully inspected for various types of endemic

injury, including basal necrosis, basal scale (unidentified), pine needle scale (Phenacaspis pinifolea), defoliators, tip necrosis, chlorotic mottle, and weevil (probably elegans pine weevil, Scythropos elegans), and the percentage of needles affected by each agent was computed and recorded. A visual, subjective estimate of the percent total surface necrosis by each agent was computed, totalled, and recorded for each group of 100 needles.

Representative specimens of the different pathology types were saved for histological analyses, killed and fixed in FAA (formalin-aceto-alcohol), sectioned by the paraffin technique (Johansen, 1940), and stained in a Feulgen's fast green schedule. Observation of the sections was done through bright-field and phase optics. Some of the specimens were processed in the EVST Laboratory; the remainder were done in the Forest Service FEP Laboratory.

Needle length was measured on 25 of each group of 100 needles and recorded. Fascicular cross-sectional area, measured just below the dwarf shoot bud, was computed on 10 intact fascicles saved previously. Moisture percentage was determined by drying a group of 25 needles for 5 days at 80° C (Centigrade). Wet and dry weights were computed and percent water was determined based on the dry weight of the tissue.

Finally, all stripped needles of a given age from each tree and crown position were prepared for chemical analysis of total sulfur and fluoride by drying in a forced draft oven at 80° C,

followed by grinding to pass a 40-mesh screen. Samples in the dried-ground state were chemically analyzed in the EVST Laboratory in Missoula (see Appendices I and II for procedural details on chemical analysis).

All fascicular sheaths previously stripped were saved for future chemical analysis. Needles previously collected for chlorophyll analysis were analyzed as outlined in Appendix III.

Understory vegetation was dried and ground for chemical analyses, but determinations of pathology and other variables were not done.

Means and standard errors were computed for each variable relative to the basic within-tree, within-crown sample, and recorded on a summary sheet (Appendix IV). Further data analysis utilized these basic values.

Ambient air concentrations of reactive sulfur and fluoride were tested at each site with lead peroxide and sodium formate plates. Two of each were attached to two of the plot trees at each site and changed bimonthly. Plates were analyzed by the Air Quality Bureau, Montana State Department of Health and Environmental Sciences.

RESULTS AND DISCUSSION

We designed this study to permit comparisons within plots and between sites distributed over a reasonably large geographic area, at varying distances from the Colstrip electric generating complex. Validity of the data for use in future comparisons is

dependent primarily on within-plot variability of each characteristic on which observations of measurements were made and the probability level chosen. Our basic premise, based on experience in other insect, disease, and air pollution studies, was that the standard error of the sample mean of a variable should be within twenty percent of that sample mean at the ninety-five percent level of confidence. It is believed that this criterion, in consideration of the costs involved, would yield information such that future possible pollution effects could be reliably diagnosed.

Sampling precision at plot #2, Beaver Creek Divide, which is typical of all plots in which data were collected, is shown in Table 2 for three age classes of foliage. Our criterion was met for all variables except for the individual pathologies. Means were so small for the latter that to increase precision to the criterion stated above, sample size would have had to be increased by more than 10; we did not consider the time and expense justifiable. Data for 1972, 1973, and 1974 needles is similar within and between plots.

During the course of our work in 1975, over 500,000 individual needles were examined and measured. This voluminous data was computer-analyzed at the University of Montana, and all analyses are on file at the EVST and Forest Service FEP Laboratories in Missoula.

A general summary of means of all plots combined, for each of the pine characteristics measured, is shown in Table 3.

Table 2

SAMPLING PRECISION AT PLOT 2,
BEAVER CREEK DIVIDE

Variable	Year of Origin 1972	1973	1974
Total chlorophyll	10.04**	8.31	8.28
Total fluoride	20.11	16.23	---
Total sulfur	9.87	8.23	9.95
Needle retention	5.07	4.69	1.90
Needle length	1.80	1.37	1.27
Cross sectional area	5.69	3.83	4.08
Percent healthy needles	17.80	15.95	11.83
Percent basal necrosis	52.72	99.52	78.94
Percent basal scale	78.72	88.65	98.28
Percent pine needle scale	152.57	---	209.67
Percent defoliators	---	209.67	144.15
Percent tip necrosis	209.20	---	162.87
Percent weevil	31.71	32.63	30.89
Percent mottled	51.11	51.67	55.64
Percent other	58.05	51.50	52.01
Percent total necrosis	34.25	33.73	32.61

**Standard error of the mean expressed as a percentage of the mean at $p = .05$; $\left(\frac{t\, s_{\bar{x}}}{\bar{x}}\right)100$.

TABLE 3

MEAN VALUES OF VARIOUS CHARACTERISTICS, BY DIFFERENT COMBINATIONS OF FOLIAGE AGE, CROWN POSITION, AND TREE AGE**

Characteristic	Foliage Age	CROWN POSITION - TREE AGE ZZ	ZY	ZO	UZ	LZ	UY	UO	LY	LO
Total fluoride, ppm, dry weight basis	All	1.48	1.49	1.46	1.47	1.47	1.49	1.44	1.48	1.49
	1975	1.14	1.06	1.22	1.22	1.06	1.12	1.33	1.00	1.11
	1974	1.46	1.45	-	1.43	1.48	1.47	1.39	1.42	1.55
	1973	1.44	1.45	1.43	1.41	1.47	1.36	1.45	1.53	1.41
	1972	1.57	1.57	1.50	1.50	1.50	1.65	1.48	1.50	1.50
Total sulfur, ppm, dry weight basis	All	483	482	484	483	483	483	484	481	485
	1975	513	527	498	509	516	518	500	536	496
	1974	501	503	-	500	502	509	490	496	508
	1973	485	483	488	480	491	476	484	490	492
	1972	460	460	467	470	456	463	478	456	455
Total chlorophyll, mg/g, fresh weight basis	All	.974	.973	.976	.965	.985	.965	.965	.982	.987
	1975	.657	.667	.646	.652	.661	.669	.634	.664	.658
	1974	.930	.928	-	.917	.944	.917	.916	.939	.948
	1973	1.016	1.015	1.018	1.012	1.021	1.009	1.015	1.020	1.021
	1972	.978	.979	.977	.966	.996	.968	.964	.989	.991

** ZZ - All crown positions, all tree ages
ZY - All crown positions, younger trees
ZO - All crown positions, older trees
UZ - Upper crown position, all tree ages
LZ - Lower crown position, all tree ages
UY - Upper crown position , younger trees
UO - Upper crown position, older trees
LY - Lower crown position, younger trees
LO - Lower crown position, older trees

TABLE 3

MEAN VALUES OF VARIOUS CHARACTERISTICS** (cont.)

Characteristic	Foliage Age	CROWN POSITION - TREE AGE ZZ	ZY	ZO	UZ	LZ	UY	UO	LY	LO
% Water	All	48.9	49.4	48.4	48.5	49.1	49.2	48.7	49.6	48.6
	1975	55.2	55.4	54.9	54.8	55.5	55.2	55.2	55.6	55.4
	1974	50.1	50.6	49.5	49.7	50.4	50.2	49.9	50.9	49.9
	1973	49.2	49.6	48.8	49.4	49.0	49.6	49.1	49.6	48.4
	1972	47.61	48.13	47.07	47.60	47.97	47.97	46.5	48.3	47.64
% Basal scale	All	7.63	7.75	7.51	7.63	7.63	7.66	7.60	7.8	7.41
	1975	.30	.22	.30	.20	.36	.20	.26	.22	.51
	1974	1.11	.99	-	1.26	.96	1.02	1.5	.96	.96
	1973	8.6	8.8	8.5	8.6	8.6	8.6	8.7	8.9	8.3
	1972	13.5	13.5	12.7	13.0	13.2	13.4	12.6	13.5	12.9
% Weevil	All	9.6	9.2	10.10	9.30	10.2	8.6	9.7	9.8	10.7
	1975	1.1	.94	1.3	1.1	1.1	.66	-	1.2	1.0
	1974	8.3	8.2	8.5	8.1	8.6	7.9	8.2	8.6	8.7
	1973	11.9	11.4	12.4	11.1	12.7	10.4	11.6	12.4	13.1
	1972	8.73	7.94	9.52	8.15	9.31	7.61	8.7	8.26	10.36

TABLE 3

MEAN VALUES OF VARIOUS CHARACTERISTICS**(cont.)

Characteristic	Foliage Age	CROWN POSITION - TREE AGE ZZ	ZY	ZO	UZ	LZ	UY	UO	LY	LO
% Needle retention	All	86.9	88.5	85.4	89.1	84.8	90.4	87.8	86.6	82.9
	1975	96.5	97.4	95.5	97.1	95.8	97.9	96.4	97.0	94.6
	1974	94.9	95.2	-	94.9	95.0	95.1	94.7	95.3	94.7
	1973	83.6	86.3	80.9	88.5	78.7	91.3	85.6	81.2	76.3
	1972	84.0	84.0	80.5	83.9	80.6	84.5	83.2	83.4	77.8
Needle length, mm	All	125.3	125.1	125.6	128.9	121.8	129.3	128.5	120.9	122.7
	1975	122.2	122.8	121.7	130.4	114.0	132.2	128.6	113.3	114.8
	1974	126.2	125.4	-	127.8	124.6	127.2	128.3	123.6	125.7
	1973	128.0	128.0	128.0	133.1	123.5	134.8	131.4	122.5	124.6
	1972	121.1	121.1	121.8	125.8	117.1	125.7	125.8	116.5	117.8
Fascicular cross-sectional area, mm^2	All	2.1	2.09	2.25	2.31	2.04	2.25	2.36	1.94	2.14
	1975	1.85	1.78	1.91	2.08	1.61	2.06	2.10	1.41	1.72
	1974	2.10	2.01	-	2.18	2.01	2.14	2.23	1.89	2.13
	1973	2.24	2.19	2.28	2.39	2.08	2.38	2.41	2.01	2.15
	1972	2.08	2.08	2.29	2.35	2.03	2.25	2.45	1.91	2.14

TABLE 3

MEAN VALUES OF VARIOUS CHARACTERISTICS**(cont.)

Characteristic	Foliage Age	CROWN POSITION - TREE AGE ZZ	ZY	ZO	UZ	LZ	UY	UO	LY	LO
% Healthy needles	All	59.6	59.6	59.6	58.8	60.4	59.2	58.4	60.1	60.8
	1975	94.6	95.0	94.2	94.8	94.5	96.0	93.5	94.0	95.0
	1974	73.2	72.3	-	71.5	74.9	71.0	72.1	73.7	76.1
	1973	54.8	54.9	54.7	54.0	55.5	54.6	53.5	55.1	55.9
	1972	51.6	51.6	50.0	50.7	50.9	51.9	49.6	51.4	50.4
% Total necrosis	All	6.7	7.2	6.1	6.5	6.6	7.2	6.4	7.6	5.9
	1975	1.0	.8	1.3	1.0	1.1	.8	1.2	.8	1.4
	1974	4.5	5.2	3.9	4.2	4.9	4.6	3.8	5.8	4.0
	1973	7.5	8.0	7.0	7.7	7.3	8.2	7.1	7.7	6.8
	1972	8.02	8.65	7.40	8.41	7.63	8.90	9.10	8.40	6.87
% Tip burn	All	3.72	4.5	2.93	3.64	3.8	4.53	2.74	4.5	3.11
	1975	.06	.1	.03	.1	.02	.17	.04	.02	.02
	1974	1.90	2.20	-	2.25	1.55	2.68	1.82	1.72	1.37
	1973	3.5	4.8	2.3	3.5	3.65	4.7	2.2	4.9	2.3
	1972	6.5	6.5	4.8	5.1	6.2	6.1	4.1	6.8	5.6

TABLE 3

MEAN VALUES OF VARIOUS CHARACTERISTICS ** (cont.)

Characteristic	Foliage Age	CROWN POSITION - TREE AGE ZZ	ZY	ZO	UZ	LZ	UY	UO	LY	LO
% Pine needle scale	All	.19	.28	.10	.19	.22	.16	.17	.40	.04
	1975	.03	.06	.00	.00	.06	.00	.00	.13	.00
	1974	.12	.16	.09	.13	.11	.12	.15	.20	.04
	1973	.38	.46	.20	.32	.43	.31	.34	.81	.06
	1972	.07	.13	.02	.03	.19	.05	.01	.20	.04
% Defoliator	All	4.2	3.9	4.40	3.80	4.30	4.0	4.1	4.0	4.70
	1975	1.2	.80	1.6	.94	1.4	.73	1.1	.86	2.0
	1974	3.0	3.0	3.0	3.0	3.0	3.2	2.9	2.9	3.2
	1973	4.1	3.9	4.3	3.7	4.5	3.8	3.7	4.0	4.9
	1972	5.44	4.89	6.00	5.41	5.47	4.94	6.2	4.82	6.12
% Other pathology	All	9.6	9.7	9.50	11.30	8.2	11.1	10.5	8.6	8.20
	1975	1.5	1.27	1.7	2.0	.96	1.6	2.4	.86	1.0
	1974	7.4	7.2	7.6	8.5	6.3	8.2	8.8	6.2	6.4
	1973	10.9	11.1	10.8	12.9	9.0	14.0	11.9	8.3	9.6
	1972	10.49	10.77	10.21	11.63	9.36	11.34	12.5	10.2	8.51

TABLE 3

MEAN VALUES OF VARIOUS CHARACTERISTICS ** (cont.)

Characteristic	Foliage Age	CROWN POSITION - TREE AGE ZZ	ZY	ZO	UZ	LZ	UY	UO	LY	LO
% Mottled needles	All	7.2	7.1	7.3	7.0	6.4	7.2	7.6	8.8	5.9
	1975	.31	.22	.40	.4	.22	.20	.60	.24	.20
	1974	5.8	6.0	5.5	6.4	5.1	6.4	6.4	5.7	4.6
	1973	7.5	7.0	8.0	8.8	6.3	7.9	9.8	6.2	6.3
	1972	8.2	8.1	8.3	8.7	7.7	7.5	12.0	7.6	6.7
% Basal necrosis	All	2.31	2.36	2.26	2.38	2.24	2.52	2.24	2.20	2.28
	1975	.27	.24	.30	.20	.30	.20	.26	.26	.35
	1974	.93	1.17	-	1.21	.64	1.76	.67	.58	.70
	1973	2.50	2.43	2.40	2.10	2.70	2.00	2.20	2.79	2.60
	1972	3.50	3.40	3.60	3.70	3.30	3.70	3.50	3.20	3.50

Nine different combinations of crown positions and tree ages and four foliar ages were used to partition the data. We have not tested statistically the differences between each of the combinations. However, on inspection of Table 3 there appears to be little influence of crown position and tree age on the mean values of the variables studied, although needle length seems to be somewhat reduced in the lower crown.

Table 3 reflects the same basic trends as found in the individual trees and plots. Sulfation and fluoridation rates were zero in every case, showing the lack of measureable airborne sulfur and fluorides in the study area, and substantiating the claim that this part of eastern Montana is truly a clean, pristine, non-polluted ecosystem. It necessarily follows that the characteristics measured on the pines represent natural conditions, have not been influenced by pollutants, and represent baseline pre-operational conditions.

Fluoride and sulfur concentrations in needles are self-explanatory and conform reasonably well to similar data from other baseline studies (Carlson and Gilligan, 1975; Gordon, 1976). The chlorophyll data show a constant, predictable pattern dependent on foliage age. Total chlorophyll is lowest in the youngest foliage (1975, with .657 mg/g) and highest in the two-year-old needles (1973 = 1.016 mg/g). Developing needles are dependent on older foliage and proteins, fats, and carbohydrates stored within the tree, and the total complement of these essential substances is not reached in young foliage for at

least one year. The chlorophyll data is discussed in depth by Meinhardt (1976). Needle retention is highest for the youngest needles but drops to 84 percent for 1972 foliage. During measurement of this characteristic, we neglected to account for scars left from pollen strobili. Thus, the 1974, 1973, and 1972 data are slightly lower than actual.[2] Also, the longer a needle is exposed to its environment, the greater the probability that insects, disease, and abiotic factors will cause injury to it. This is demonstrated vividly in Table 3. It follows that should these agents accelerate the abscission process, affected needles will fall prematurely. Thus, we expect that as age of internode increases, needle retention will decrease. In a non-polluted area with endemic insects and diseases, premature needle loss is expected to be minimal. Because this is the case in our study, the needle retention data is interpreted to reflect true baseline conditions.

Needle length and fascicular cross-sectional area were lowest for needles originating in 1975. This was expected because new pine needles begin elongating in May and continue longitudinal and transverse growth into August and September. More than half our measurements were taken before growth ceased.

Percent healthy needles decreased with age, as would be expected. In this study, a healthy needle was <u>completely</u> green,

2. Needle retention estimates were redone on plots 13 and 14 and pollen strobili scars were accounted for. A difference of only 2-5% from the original estimate was noted.

without any necrosis or chlorosis or other visible pathology. Many biotic (fungi, insects, bacteria) and abiotic (heat, wind, water, etc.) agents exist that can cause damage to pines and other flora. We selected for quantification a few key insect and abiotic symptoms. It was virtually impossible to diagnose the precise cause of each lesion found, but the categories we used at least indicate in a general way the types of injury present. The incidence of each type of injury was very low; generally less than 10 percent of the needles were affected by any one agent. Collectively, however, up to 50 percent of the older (1972) needles were affected by the various agents. One's first impression is to visualize the entire area as consisting of unhealthy pines, but the measurement of percent total necrosis on affected needles refutes this false deduction. Total necrosis never exceeded 10 percent overall, even in the older needles -- 90 percent or more of the surface area was still green. This readily substantiates our field observation that pines on the Ashland Division, Northern Cheyenne Indian Reservation, and private lands near Colstrip are some of the greenest, most vigorous we have seen in Montana.

As mentioned before and reflected in Table 3, the injury caused by the different agents increases with increasing needle age. Because all plots were combined in arriving at these mean values, sample size was large and the standard errors relatively small (see Appendix VI for example of variability). Thus, the sample means are likely close to the true population means.

Tip burn can be caused by extreme cold, drought, heat, air pollution, or other abiotic agents. Histologically, the air pollutant-related tip burn can be separated from the others.[3] The relationship of basal necrosis and basal scale is less well known. Basal necrosis, or necrotic lesions found near the needle bases, can be caused by acids such as those formed near sources of air pollutants. Other factors may also be responsible; it is hoped that this problem will be resolved this year.

Basal scale is a term given to the injury caused by Matsucoccus, a small scale insect that inhabits the fascicular sheath of several pine species, including ponderosa pine. Injury by this insect includes a slit-like lesion and associated swelling, but recent observations indicate that other insects may be associated with this type of damage.[4] Figure 2 shows the tentative distinction between basal scale and basal necrosis.

Percentages of weevil, pine needle scale, and defoliator were small. The relationship of these insects to future pollution in the Colstrip area is obscure. However, pine needle scale has been observed epidemic in areas polluted by smelter fumes and high dust concentrations and may be a good indicator of declining tree vigor. The weevil and defoliators were present in the area, and we thought it wise to estimate current injury caused by them.

3. Laboratory and field studies by C. C. Gordon and C. G. Carlson, soon to be published.
4. Studies in progress by Dr. Jerry Bromenshenk, University of Montana.

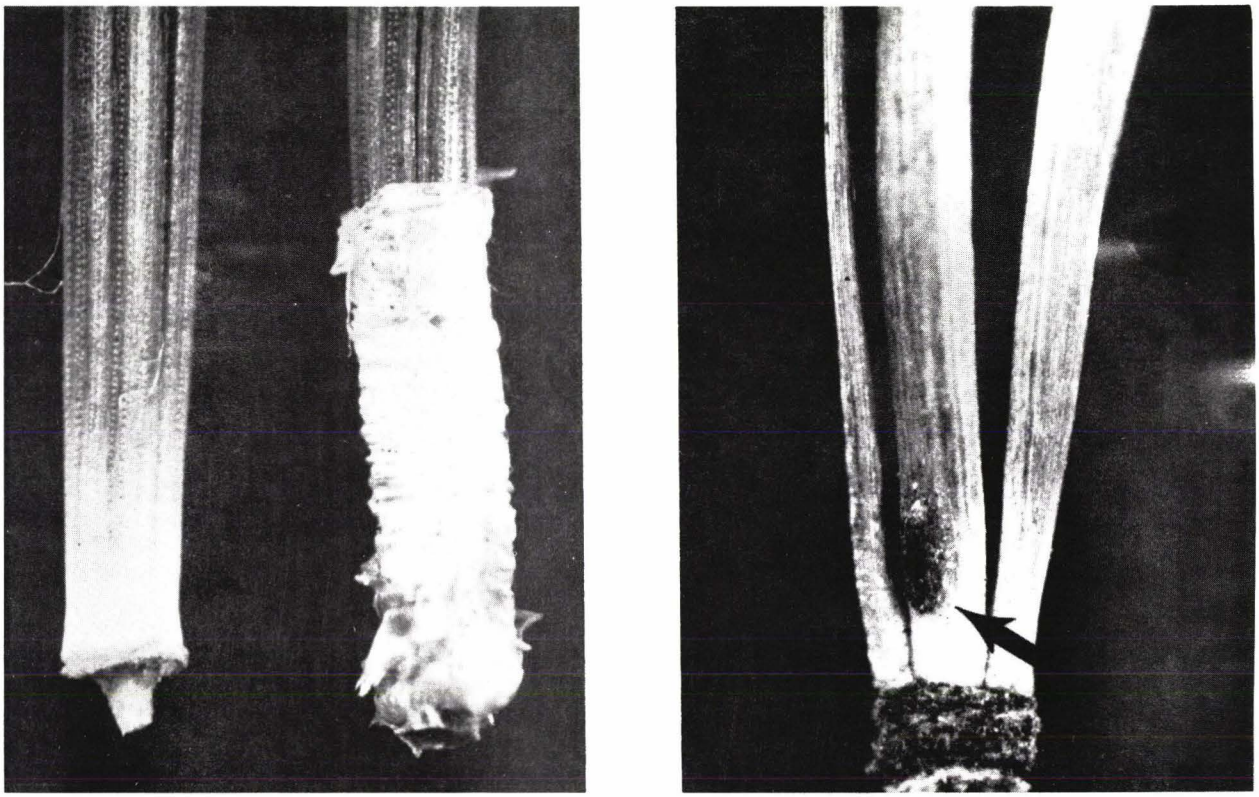


Figure 2. Macroscopic difference between basal scale and basal necrosis. Upper left - healthy; upper right - basal scale; lower left basal necrosis. Note the oval shaped, necrotic swelling associated with basal scale. This is not found with basal necrosis.

An index relating total % needle necrosis and % "unhealthy" needles was developed in order to facilitate the estimation of the general relationship regarding total necrosis and % unhealthy needles within individual plots, as well as over all of the plots. The index is calculated as the product of proportion of unhealthy needles X proportion total necrosis X 100. Thus, if the maximum proportion unhealthy needles (Table 3, ZZ) is multiplied by the maximum proportion total necrosis, and that product is multiplied by 100, the following is obtained:

$$(.4 \times .07)\ (100) = 2.8,$$

giving an index of 2.8, overall, for all years' needles from all plots.

This index may be a very sensitive indicator of future pollution insults. It is noted that by increasing the percent unhealthy needles to 60% and the percent total necrosis to 10%, a condition which may occur due to increased tip burn, basal necrosis, or other pollution-related injury, the index is increased to 6. Thus, increasing percent unhealthy needles and percent necrosis by factors less than 1/2 increases the index by a factor more than 2.

Furthermore, the index is particularly sensitive to low levels of necrosis over a large number of needles. For example, if a sample of 100 needles contained 10 <u>totally</u> dead, necrotic individuals, the total necrosis would be 10%, while the index would be 1.0. If all of the needles in the sample contained 10% tip burn, the total necrosis would also be 10%, while the index increases to 10.0.

On Table 4 are shown indices for each year's needles for plots 5, 7, 10, and 14 and for all plots combined. Those data which individually and collectively make the greatest contribution to decreased percentages of healthy needles and to increased percentages of total necrosis are shown in Table 5 for the same plots.

Inspection of Table 4 reveals that the indices for plots 5, 7, and 10 deviate positively from the overall average, while those for plot 14 are less, except for 1975. Table 5 shows that pathologies other than tip burn were greatest in plots 5 and 10, while tip burn is greatest in plot 7. For plots 5 and 10, the raw data shows that pathologies for categories other than tip burn are responsible for the elevated indices at these plots. For plot 10, tip burn on 1972 and 1973 needles from three or four individual trees contributed to the elevated indices, but the other categories contributed overall.

It should be noted at this juncture that plot 5 was subjected to a severe storm, with winds estimated to approach 100 miles per hour in the spring of 1975. The winds were strong enough to strip bark from ponderosa pine.

It is reiterated that the means for pathology characteristics within individual plots are not precisely known (Table 2). However, the index permits rapid measure of the extent of the deviation of individual plots from the total population means, and therefore the probable cause(s) of the deviation is easily determined and can be evaluated quickly. This is of salient

TABLE 4

INDICES FOR INDIVIDUAL YEARS' NEEDLES
FOR PLOTS 5, 7, 10, and 14, AND ALL PLOTS COMBINED*

Plot #	Year of Foliage Origin 1972	1973	1974	1975
All Plots	3.8	3.4	1.2	.05
Plot 5	11.6	10.9	10.77	--
Plot 7	8.9	6.37	1.01	.06
Plot 10	9.79	6.69	.49	.08
Plot 14	2.44	1.87	.60	.12

* Indices were calculated from the category ZZ, all combinations of tree age and crown position.

TABLE 5

VARIABLES WHICH CONTRIBUTE TO LOWERED % HEALTHY NEEDLES
AND ELEVATED PERCENTAGES OF TOTAL NECROSIS
FOR PLOTS 5, 7, 10 AND 14 AND ALL PLOTS COMBINED

Plot #	% Healthy Needles	% Total Necrosis	% Tip Burn	% Mottle	% Weevil	% Other Pathology
#5 -- 1975	-	-	-	-	-	-
1974	33.9	16.35	4.9	20.3	17.5	26.9
1973	37.6	17.6	.5	23.6	12.1	32.1
1972	32.2	17.1	1.0	26.7	9.7	34.4
#7 -- 1975	95.4	1.35	.05	0.0	1.55	1.9
1974	73.3	3.8	9.95	0.0	5.85	6.55
1973	39.3	10.5	16.8	3.6	12.1	12.7
1972	25.8	12.0	26.5	3.0	6.7	15.6
#10 -- 1975	93.6	1.31	.1	.1	1.75	2.15
1974	82.7	2.8	.55	1.15	5.1	7.2
1973	46.5	12.5	1.1	2.1	12.6	17.8
1972	35.8	15.2	1.75	2.2	5.5	16.6
#14 -- 1975	89	1.05	0.0	.15	.95	2.8
1974	79.7	2.9	.9	4.2	4.4	4.2
1973	65.0	5.3	.35	8.0	8.0	3.3
1972	61.9	6.4	.3	2.3	4.9	3.0
All Plots--1975	94.6	1.0	.06	.31	1.1	1.5
1974	73.2	4.5	1.9	5.8	8.3	7.4
1973	54.8	7.8	3.5	7.5	11.9	10.9
1972	51.6	8.0	6.5	8.2	8.7	10.5

importance in this study, since plot 14, which has indices less than the overall average (Table 5), is less affected by pathologies and is presumably one of the "healthier" plots, lies 16 miles downwind from the coal-fired steam-electric generating complex at Colstrip. Further, plots 12 and 13 lie 3 and 10 miles downwind, respectively (Table 1). These plots have the potential to be impacted by air pollutants before any others. This study design, which permits the determination of general conditions over all of the plots, has the flexibility to detect deviations which would be expected to result from air pollution impact on the plots individually and collectively.

The value of the pine characteristics we chose to measure as pollution indicators can be substantiated in part by comparisons to similar measurements made in other studies in polluted and non-polluted areas. Basal needle necrosis/basal scale is much more prevalent near sources of air pollution. Gordon (1976) found up to 85 percent basal necrosis near a bromine-emitting source in Arkansas. In a related field evaluation, he found between 98-100% basal necrosis 1/2 mile from an aluminum plant at The Dalles, Oregon, and 32-86%, 3 3/4 miles downwind. The basal necrosis/basal scale syndrome was also observed in a high proportion (65%) near Billings, Montana, which is the site of a small coal-fired power plant burning coal from the same source as the Colstrip units and several oil refineries. Collectively, these industries emit phytotoxic quantities of sulfur oxides and fluorides to the atmosphere, similar to expected emissions at Colstrip. In similar

studies on white pine (Pinus strobus) and Scotch pine (Pinus sylvestris) Gordon found between 52-78% basal necrosis near a large, coal-fired power plant in West Virginia.[5]

Control data from another baseline study in eastern Washington compare favorably with our Colstrip data (Carlson and Gilligan, 1975). In that field study, less than 1% basal necrosis was found. These relationships are shown graphically in Figure 3, strongly indicating the direct relationship between increasing air pollution of different types and the basal necrosis/basal scale complex.

A comparison of needle retention data at polluted and non-polluted sites in the United States is shown in Figure 4. Needle retention near a large coal-fired power plant in West Virginia is much lower than in "clean" areas in western Montana and eastern Washington. Scheffer and Hedgecock (1955), in field studies conducted during the early part of this century, noted premature needle drop on conifers near sulfur-emitting sources, and Carlson et al. (1974) documented premature needle casting of conifers near a sulfur-emitting pulp mill in western Montana.

The value of needle length, fascicular cross-sectional area, and percent water as pollution indicators is not known at this time. Comparative studies need to be done between clean and polluted areas to better assess their potential.

5. Data from Arkansas, Billings, The Dalles, Oregon, and West Virginia are on file in the EVST Laboratory in Missoula.

FIGURE 3

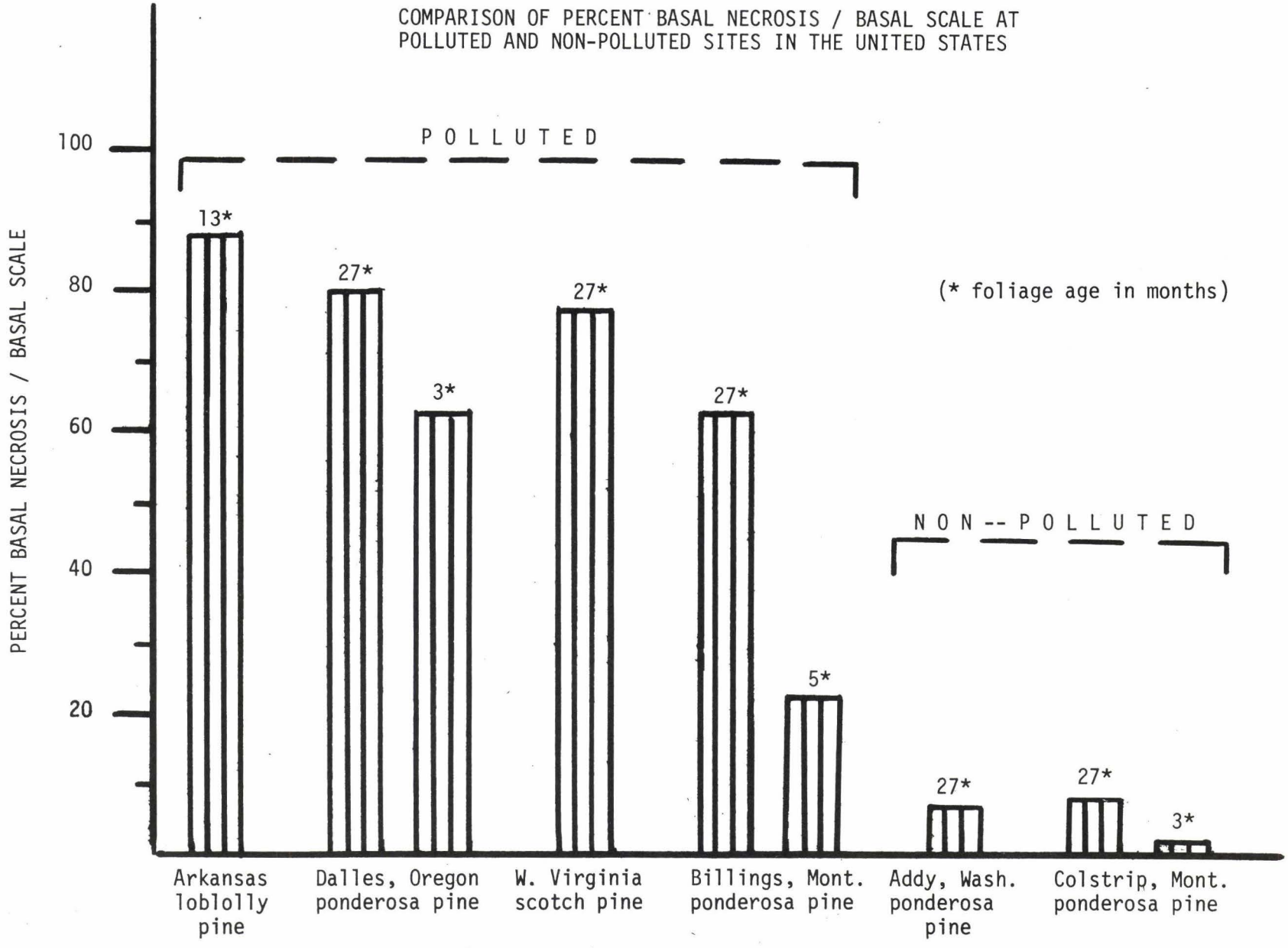
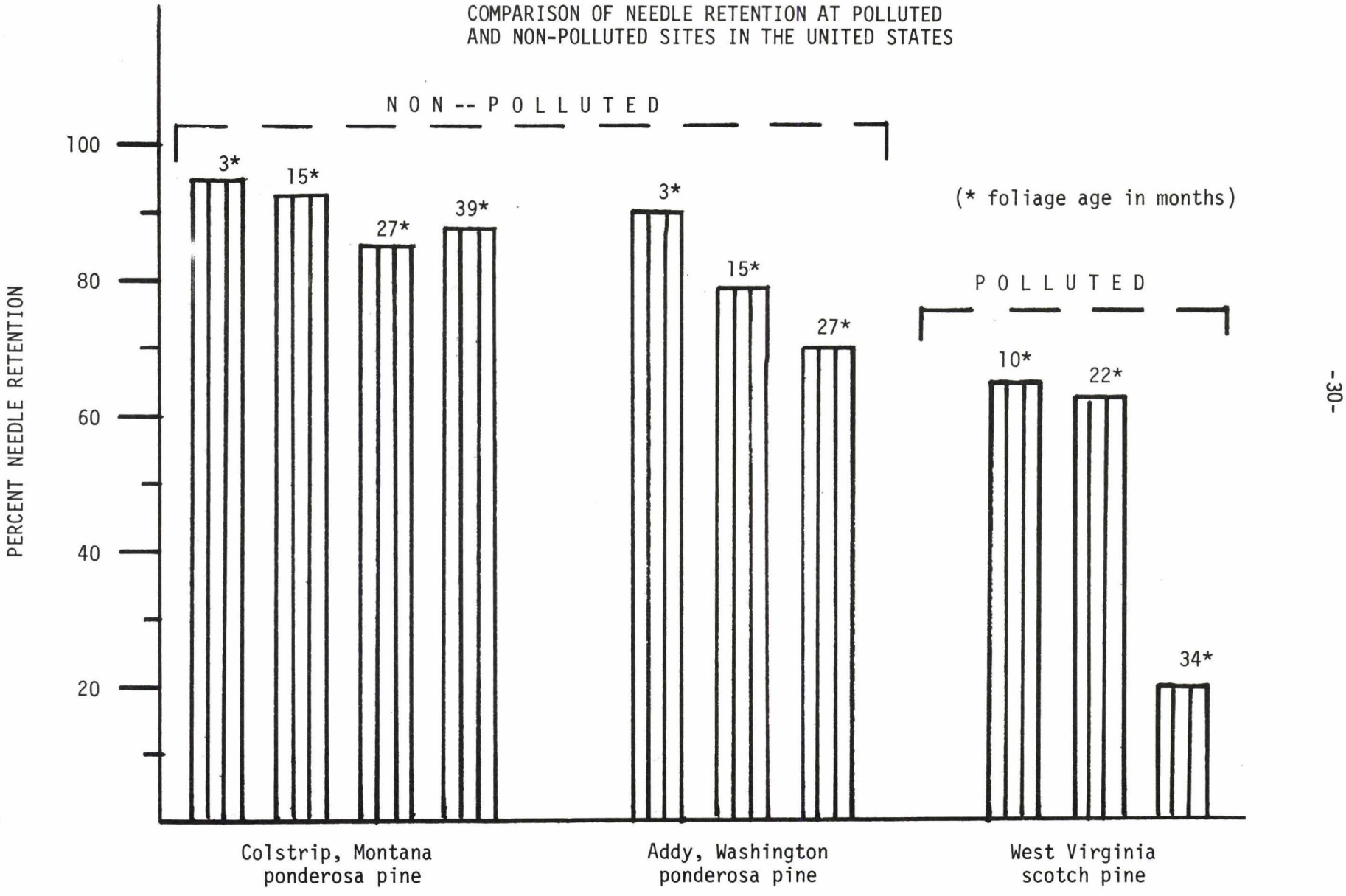

COMPARISON OF PERCENT BASAL NECROSIS / BASAL SCALE AT
POLLUTED AND NON-POLLUTED SITES IN THE UNITED STATES
PERCENT BASAL NECROSIS / BASAL SCALE
100
80
60
40
20
POLLUTED
NON--POLLUTED
13*
27*
3*
27*
27*
5*
27*
27*
3*
(* foliage age in months)
Arkansas loblolly pine
Dalles, Oregon ponderosa pine
W. Virginia scotch pine
Billings, Mont. ponderosa pine
Addy, Wash. ponderosa pine
Colstrip, Mont. ponderosa pine

FIGURE 4


COMPARISON OF NEEDLE RETENTION AT POLLUTED AND NON-POLLUTED SITES IN THE UNITED STATES
NON--POLLUTED
POLLUTED
(* foliage age in months)
PERCENT NEEDLE RETENTION
100
80
60
40
20
3*
15*
27*
39*
3*
15*
27*
10*
22*
34*
Colstrip, Montana ponderosa pine
Addy, Washington ponderosa pine
West Virginia scotch pine

In October, 1975, three trees which were located in an area known to be impacted by air pollutants from the Corette Steam Plant were sampled from the upper crown, on the sides facing towards and away from the steam plant. The results of measurements and observations on eleven characters for 1973 foliage are presented in Table 6. For two of the three trees, % needle retention is less on the side facing the plant, total necrosis is greater on the side facing the plant, and the sampled needles had a smaller cross-sectional area on the side facing the steam plant. For all trees, the needles were shorter on the side facing the plant, the % tip burn was greater on the side facing the plant, and the % healthy needles was less on the side facing the plant. Fluoride and sulfur were measured on only one tree. Sulfur was about the same on both sides of the tree, while fluoride was 117 ppm on the side facing the plant and 19.4 ppm on the side facing away.

During the 1976 portion of this study, a sampling plot will be established at Billings in the vicinity of these trees, of the same design as the other 16 plots.

Fluoride and total sulfur concentrations in conifers are known to increase in plant tissue near sources of those compounds. Data concerning effects on chlorophyll are conflicting. Meinhardt (1976), in attempting to clarify the usefulness of chlorophyll as an indicator of pollution, concluded that total chlorophyll, chlorophyll a or b, or the ratio of a to b likely would not be good characters. However, other literature in her report

TABLE 6

RESULTS OF DETERMINATIONS OF SELECTED VARIABLES
FROM 3 TREES AT BILLINGS, MONTANA
1973 FOLIAGE

Parameter	Tree #2051 A*	Tree #2051 B*	Tree #2056 A	Tree #2056 B	Tree #2061 A	Tree #2061 B
Fluoride (ppm)	117	19.4	-**	-**	-**	-**
Sulfur (ppm)	1500	1550	-**	-**	-**	-**
% Needle retention	74	79	92	91	49	93
% Healthy needles	8	33	55	35	5	18
% Total necrosis	11	9	6	19	16	9
% Tip burn	73	45	2	0	11	2
% Mottle	0	0	0	0	0	0
% Weevil	2	3	14	11	4	5
% Other pathology	6	3	0	20	45	32
Needle length (mm)	112.4	136.6	129.7	149.4	181.8	189.4
Needle cross-sectional area (mm^2)	2.99	3.54	2.76	4.07	4.19	3.90

* A = Side of crown facing Corette Steam Plant
  B = Side of crown facing away from Corette Steam Plant
**Samples for fluoride and sulfur were lost in a fire

indicate otherwise, and the consistency of the chlorophyll data in Table 3 of this report demonstrates that it is premature at this time to exclude chlorophyll as an indicator, although it perhaps may not be the most sensitive character.

Results of chemical analyses on understory species are shown in Table 7. These data support the baseline nature of fluoride determinations done on the pines. However, total sulfur is considerably more variable. For example, fringed sage varies from 500 ppm to 1450 ppm between plots, and arrowleaf balsam root contained up to 2300 ppm sulfur. Because of this variability, it is questionable how valuable the dicot and monocot sulfur parameter will be in assessing the extent of airborne sulfur from Colstrip. Even so, total sulfur in grasses collected at the ZAP site[6] in 1975 was exceptionally high (5280 ppm in Agropyron smithii), reflecting the rapid accumulation of airborne sulfur dioxide. Thus, under polluted conditions, the magnitude of sulfur accumulation by angiosperms may be great enough that differences between baseline and polluted conditions can be observed.

Histological studies of needles' bases with basal necrosis-basal scale disclose two distinct tissue disease syndromes which occur beneath the fascicular sheaths (cataphylls) of ponderosa pine needles. The disease condition called basal scale occurs not only beneath the fascicular sheath but also just above (1 mm)

6. ZAP -- Zonal Air Pollution study by EPA in the Fort Howes District, Custer National Forest.

TABLE 7
SULFUR AND FLUORIDE CONCENTRATIONS
IN SHRUBS, FORBS AND GRASSES

Species	Sites						
	CNF 1	CNF 2	CNF 3	CNF 4	CNF 5	CNF 6	CNF 7
	ppm F⁻ ppm S	ppm F⁻ ppm S	ppm F⁻ ppm S	ppm F⁻ ppm S	ppm F⁻ ppm S	ppm F⁻ ppm S	ppm F⁻ ppm S
Silver Sage	2.3 1300.0	2.6 1400.0	- -	2.0 1050.0	- -	3.0 1300.0	2.7 1550.0
Broom Snakeweed	- -	3.4 2000.0	- -	- -	2.0 950.0	1.5 1675.0	2.5 1150.0
Chokecherry	1.8 650.0	- -	1.2 700.0	3.9 300.0	1.8 500.0	- -	2.6 450.0
Skunkbush	6.4 950.0	1.4 1000.0	3.5 850.0	.9 550.0	2.1 950.0	1.9 950.0	1.6 950.0
Idaho Fescue	.8 700.0	2.6 800.0	1.2 450.0	1.4 400.0	1.5 650.0	- -	2.4 650.0
Bluebunch Wheatgrass	1.1 800.0	2.7 600.0	2.7 600.0	.2 750.0	.4 700.0	2.8 1100.0	2.5 800.0
Prairie Sage	2.2 900.0	1.8 1100.0	2.1 850.0	4.8 650.0	3.3 950.0	5.7 1150.0	2.5 800.0
Fringed Sage	1.6 1150.0	1.4 1400.0	3.1 1350.0	4.0 500.0	2.5 1450.0	2.4 1200.0	1.9 1450.0
Arrowleaf Balsamroot	- -	1.4 1000.0	- -	- -	3.1 2300.0	4.9 1150.0	- -
Unknown Shrub	1.6 900.0	1.0 2100.0	- -	3.6 700.0	2.3 900.0	- -	2.7 950.0
Little Bluestem	- -	- -	.5 250.0	.7 400.0	- -	- -	- -
Crested Wheatgrass	- -	- -	1.9 800.0	- -	- -	- -	- -
Sweet Clover	- -	- -	4.8 250.0	- -	- -	- -	- -
Lupine	- -	- -	2.9 1000.0	- -	- -	2.1 1100.0	- -
Yucca	- -	- -	- -	- -	- -	2.8 800.0	- -

TABLE 7
(continued)

Species	Sites						
	CNF 8	CNF 9	CNF 10	CNF 11	CNF 12	CNF 13	CNF 14
	ppm F^- ppm S	ppm F^- ppm S	ppm F^- ppm S	ppm F^- ppm S	ppm F^- ppm S	ppm F^- ppm S	ppm F^- ppm S
Silver Sage	1.6 1275.0	2.7 1150.0	4.5 1300.0	1.1 850.0	1.3 1300.0	2.0 1400.0	- -
Broom Snakeweed	6.6 1550.0	4.3 1400.0	3.9 1900.0	2.7 750.0	- -	2.2 1800.0	- -
Chokecherry	- -	- -	- -	- -	- -	2.5 600.0	.7 300.0
Skunkbush	1.9 750.0	2.3 750.0	1.3 550.0	3.2 750.0	1.8 1800.0	4.1 800.0	3.6 600.0
Idaho Fescue	3.5 750.0	1.3 700.0	3.1 500.0	- -	- -	- -	- -
Bluebunch Wheatgrass	3.7 650.0	3.3 750.0	1.9 1600.0	1.8 750.0	1.1 500.0	2.1 600.0	- -
Prairie Sage	3.7 750.0	1.3 900.0	1.9 1000.0	- -	4.8 900.0	- -	1.9 650.0
Fringed Sage	2.1 1100.0	2.1 950.0	4.1 1200.0	- -	.9 1000.0	4.2 1100.0	4.0 650.0
Arrowleaf Balsamroot	4.0 1600.0	- -	- -	- -	- -	- -	- -
Unknown Shrub	- -	1.1 1000.0	- -	- -	- -	- -	2.5 725.0
Little Bluestem	- -	- -	2.6 300.0	- -	2.5 300.0	2.3 400.0	1.2 300.0
Lupine	- -	- -	- -	2.0 950.0	- -	- -	4.9 750.0
Scurf Pea	2.6 850.0	- -	4.1 1100.0	- -	2.8 950.0	1.9 900.0	- -
Serviceberry	2.4 750.0	- -	- -	- -	- -	- -	- -

TABLE 7
(continued)

Species	Sites		
	CNF 15	CNF 16	CNF 17
	ppm F^- ppm S	ppm F^- ppm S	ppm F^- ppm S
Chokecherry	- -	1.2 500.0	- -
Idaho Fescue	- -	1.6 700.0	- -
Prairie Sage	- -	3.5 500.0	- -
Scurf Pea	- -	.7 800.0	- -
Dogbane	1.7 800.0	- -	- -
Hazlenut	.5 800.0	- -	- -
Cheatgrass	1.1 600.0	- -	- -
Buckbrush	.9 400.0	- -	- -
Unknown Grass	- -	2.3 700.0	2.7 300.0
Oak	- -	2.6 1000.0	- -
Cinquefoil	- -	- -	5.9 250.0
Kinnikinnick	- -	- -	5.4 350.0
Unknown Sage	- -	- -	3.4 200.0
Quaking Aspen	- -	- -	.9 500.0

TABLE 7
(continued)

Species	Sites						
	CNF 8	CNF 9	CNF 10	CNF 11	CNF 12	CNF 13	CNF 14
	ppm F^- ppm S	ppm F^- ppm S	ppm F^- ppm S	ppm F^- ppm S	ppm F^- ppm S	ppm F^- ppm S	ppm F^- ppm S
Big Sage	2.3 950.0	- -	- -	- -	- -	- -	- -
Red Three Awn	- -	- -	- -	- -	2.9 500.0	- -	- -
Needle-and-Thread	- -	- -	- -	1.0 1450.0	2.7 700.0	2.2 1100.0	- -
Vetch	- -	- -	- -	- -	2.4 1200.0	- -	- -

the sheath, and is identified macroscopically and/or microscopically by either an eruption (splitting) of the epidermal and hypodermal tissue or by a small localized enlargement (blister) of the mesophyll tissue, which causes the hypodermal and epidermal tissues of the needle to be pushed out into a blister. These two symptoms (i.e., splitting of the hypodermal and epidermal tissues and the small localized blister) often occur together.

Basal necrosis is more common at the very base of the needle, where the fascicular sheath and needle are joined, or between the needles in the axis where the dwarf shoot bud is located. The overall color of basal necrosis is pale to dark brown, and no blisters or visible splitting are evident.

Mottling is simply the presence of localized chlorotic or brown areas of different sizes and shapes on an otherwise green needle. This symptom is caused by the death of chlorophyll-containing mesophyll cells located beneath the epidermal and hypodermal tissues of the needles. This symptom can be caused by a variety of causal agents, such as sucking or burrowing insects, fungi, air pollutants, hail, etc.

Needle tip burn is caused by loss of the green pigment chlorophyll in the apical portion of needles. The amount of tip burn varies dramatically depending upon the causal agent(s) causing this needle tip necrosis. Tip burn or tip necrosis is manifested in colors of light yellow to dark brown and although some plant pathologists, entomologists, and air pollution investigators claim they can differentiate the causal agent

based upon the color of the tip burn, we disagree, and no attempt to utilize color differentiation for the causal agent(s) was utilized in this study.

Histology on other types of needle pathology, such as defoliator, pine needle scale, and weevil, was also done, but is not considered here.

The outward appearance of needle basal scale and basal necrosis is shown in Figure 2. Microscopically, basal needle tissues and fascicles are shown in photo plates 1 and 2, depicting these various tissues in cross- and longitudinal sections. Meristematic cells are located in the immature basal tissue of pine species, and because of their mitotic condition are susceptible to pollution damage in the early morphogenesis of pine foliage. Cells in this region of the needle remain thin-walled, uncutinized, and undifferentiated for longer periods (i.e., 60 to 90 days) than any other portion of the pine needles.

Because the fascicular sheath is similar in shape and function to a deep water vase and is perennial in nature (except in five-needle pines), some insects find this a suitable home for a portion of their life cycle, particulate is washed or blown into this tissue (between the needles and fascicular sheaths), and precipitation containing weak and strong acids can collect in this area of the needle easier and can be retained longer than in other areas of the needles.

On plates 3 to 5 are photomicrographs of the basal tissues of ponderosa pine manifesting the symptoms of basal scale. As is noted in the two plates with longitudinal sections (i.e., plates 4 and 5), hypertrophy (cell enlargement) of the mesophyll cells has occurred, which causes the "blister"-like appearance depicted in Figure 2. In photomicrographs of cross sections (plate 5) one notes that the hypertrophy of the mesophyll cells causes splitting of the hypodermal and epidermal tissue. This splitting opens up the needle so that the inner thin-walled cells are more prone to attack by saprophytic fungi and some insects.

Currently we have not identified the causal agent(s) of the disease classified by us as basal scale, but studies are continuing and several insects and mites are being considered for isolation and innoculation studies later this year.

Plates 6 to 8 depict the tissue pathologies of basal necrosis. On plate 6 are cross-sections of pine needle tissues at the very base (below and at the point of the dwarf shoot bud attachment) which show the cellular necrosis which occurs to tissues and cells on the interface of needles deep in the fascicular sheath. This tissue necrosis of interfacial areas disrupts normal differentiation, and the needles do not separate with the normal development of the epidermal cells. Also, this cellular and tissue necrosis allows for easier entry by saprophytic fungi, insects, and strong or weak acidic precipitation. On plate 7 are cross sections of necrotic pine needle bases taken at and

above the point of dwarf shoot bud location. The outer thin-walled cells (parenchymatous cells) of the dwarf shoot bud (photos 1 and 2, plate 7) are necrotic, as are the mesophyll cells of two of the three needles in this needle set. In the other two photomicrographs of this plate (photos 3 and 4, plate 7), a large amount of particulate is lodged between the three needle interfaces of the needle set as well, and necrosis of the mesophyll tissue is located along the hypodermal tissues of each of the three needles. Particulate, especially soluble particulate, is expected to play a major role in basal necrosis of the pine needles located and growing in close proximity to large stationary pollution sources. On plate 8 are photomicrographs which depict the partial "burnout" (necrosis) of a dwarf shoot bud in longitudinal section. As can be seen in three of these photos, both the parenchymatous cells of the apex of the dwarf shoot bud and beneath the dwarf shoot bud are necrotic. The last photo on this plate (photo 4) shows necrosis of mesophyll tissues beneath the hypodermal and epidermal tissues. This cellular necrosis can be compared with the cellular response (hypertrophy) on plate 3, photos 1-3, of basal scale, elucidating the differences between basal scale and basal necrosis.

As previously described, needle mottling is defined as localized mesophyll necrosis of different sizes and patterns in otherwise green needles. On plate 9 are longitudinal sections of a mottled needle from plot #3. Selected mesophyll cells are necrotic and totally collapsed in areas of the needle where

adjacent mesophyll cells are turgid and healthy. The loss of the chlorophyll and death of these selected mesophyll cells beneath the epidermis and hypodermis are the reason for the mottling appearance which is visible to the viewer. Cause of the mottling is unknown.

Ponderosa pine foliage manifesting tip necrosis in older needles (1972 and 1973) was not abundant, but still present at most of our plots. Histological studies of needles with tip necrosis collected from our Custer National Forest sites have not disclosed any abnormal necrotic tissue pathology other than normal senescence. However, from ponderosa pine samples collected in the immediate vicinity of Colstrip and our Billings site next to the Corette 180 mW power plant, the tissue pathology of necrotic needle tips was caused by phytotoxic gases. Photo plate 10 illustrates the tissue pathology of ponderosa pine needles damaged by gaseous fluoride and sulfur emissions on Sacrifice Bluff at Billings, Montana. The zone between necrotic and non-necrotic mesophyll cells is sharply delineated across the entire needle, and necrosis and/or hypertrophy of vascular tissues (center of needle) has proceeded deep into the green area (non-necrotic mesophyll tissue area) of this 2 mm needle section. This deeper penetration of the phytotoxic effect into the vascular tissue than into the mesophyll tissue is known to be caused by sulfur, fluoride, and bromine gases, but not by such phytotoxic gases as ozone, chlorine, and NH_3 nor by other abiotic causal agents such as frost, drought, and natural senescence.

We believe our past and current histological studies on conifer foliage in air polluted and clean areas will allow us to ascertain what causal agents have caused the damage and to truly define the limits of pollution insults.

In early August, 1975, one of us (Carlson) accompanied Mark McGregor, leader of the Bark Beatle Evaluation and Control Group, FEP, on an inspection trip to eight of the study plots, including 12 and 13. The purpose of the trip was to determine the current status of those insect species present at the plots and their potential for future buildup. The result of the evaluation was that with the exception of plot 10, no insects were observed which might have a potential for buildup to epidemic levels during 1975-1976. McGregor's report is included as Appendix VII.

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Description of Photo Plates

Plate 1. Cross sections of healthy fascicle, above dwarf shoot bud.

Plate 2. Longitudinal sections of healthy fascicle.

Plates 3 & 4. Longitudinal sections of basal scale.

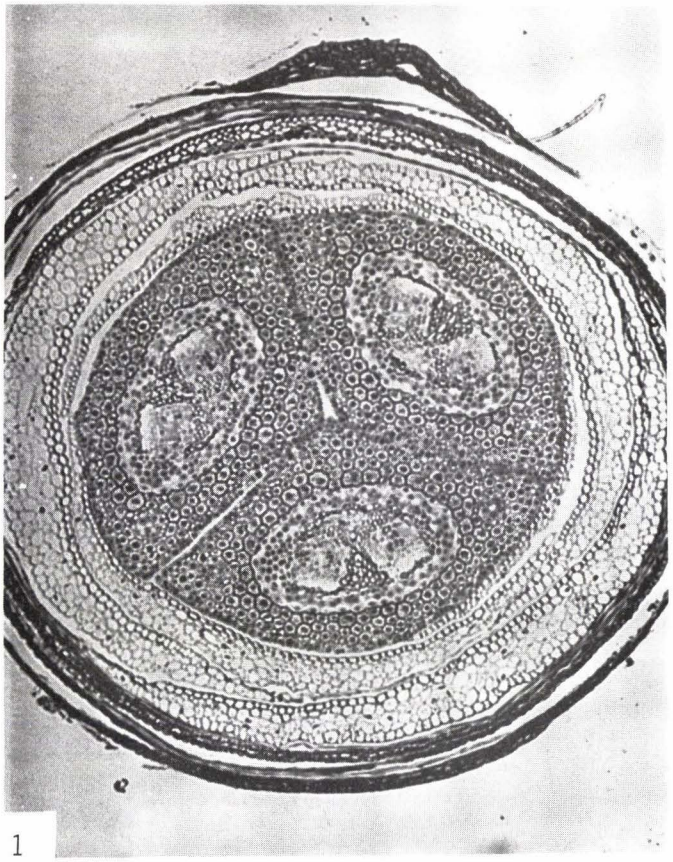
Plate 5. Cross sections of basal scale.

Plates 6 & 7. Cross sections of basal necrosis.

Plate 8. Longitudinal sections of basal necrosis, including dwarf shoot bud.

Plate 9. Longitudinal sections of mottling.

Plate 10. Longitudinal sections of tip burn incited by sulfur dioxide and fluoride.



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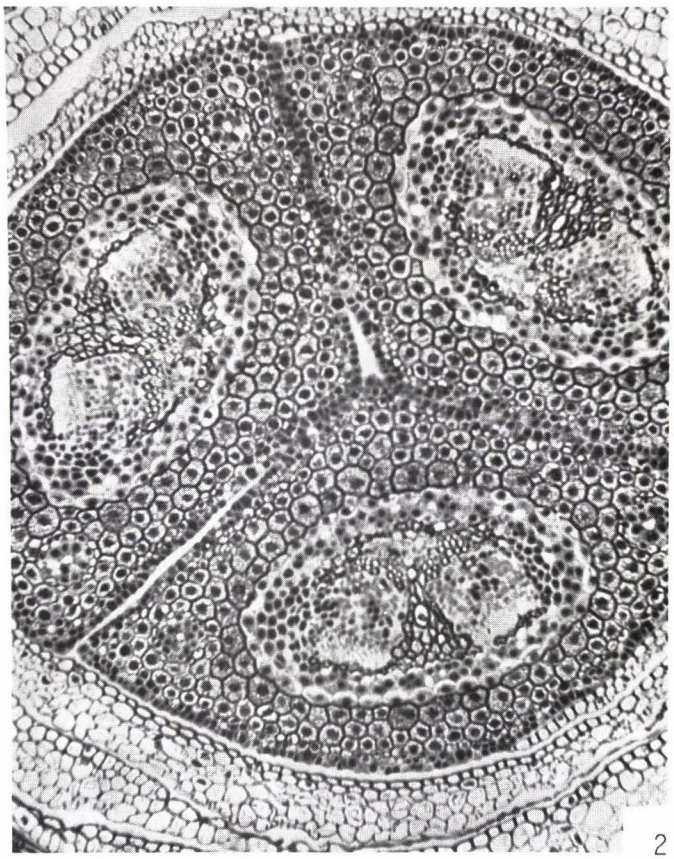

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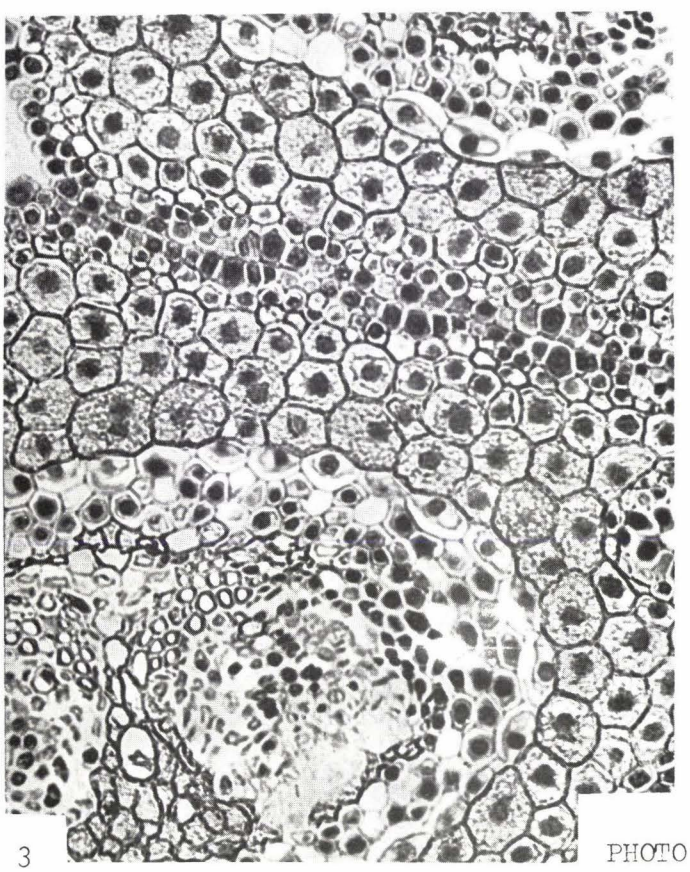

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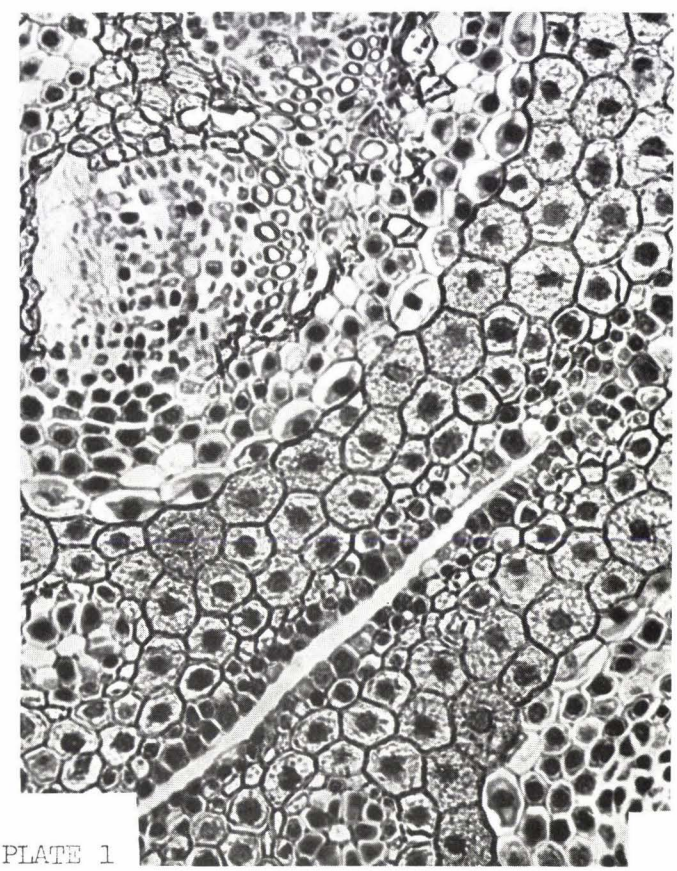

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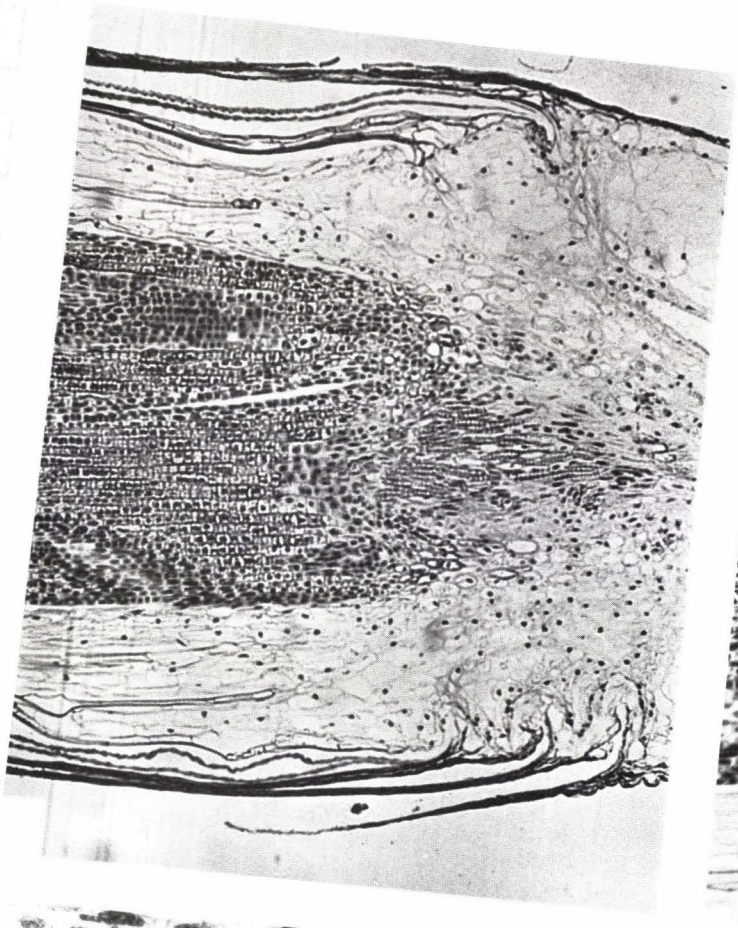

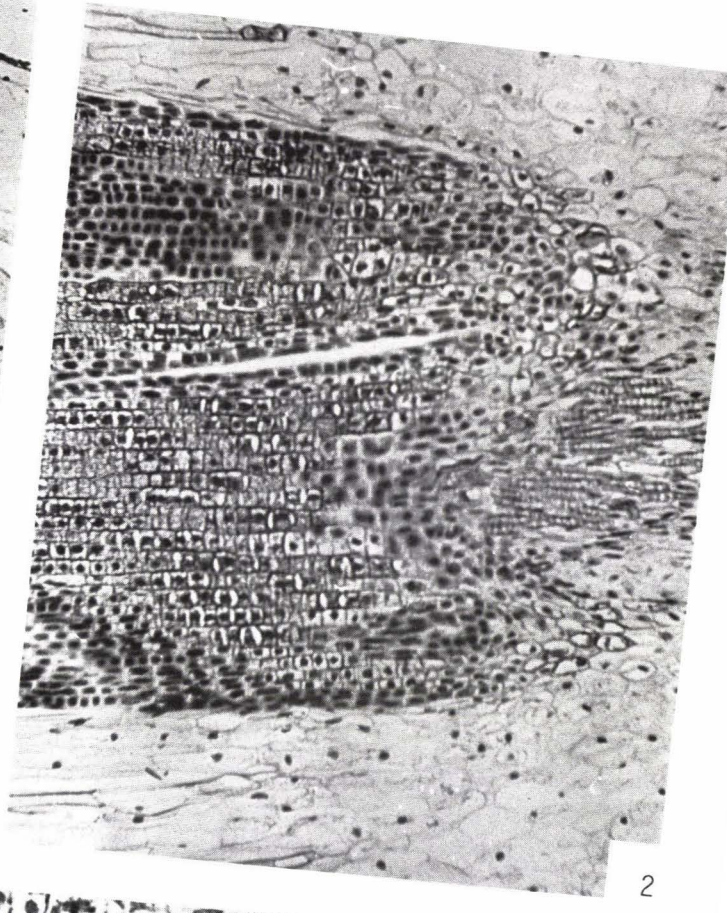

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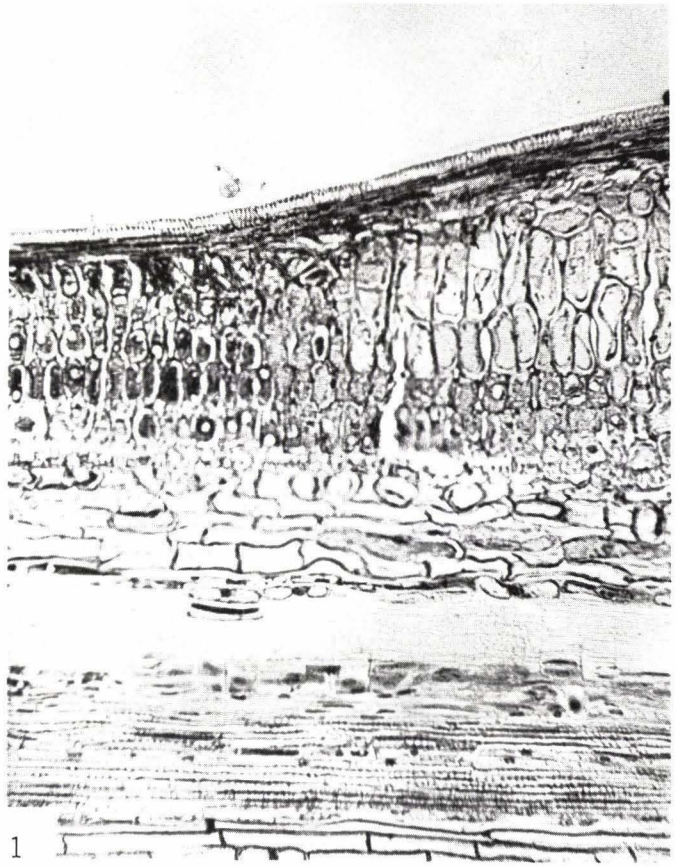

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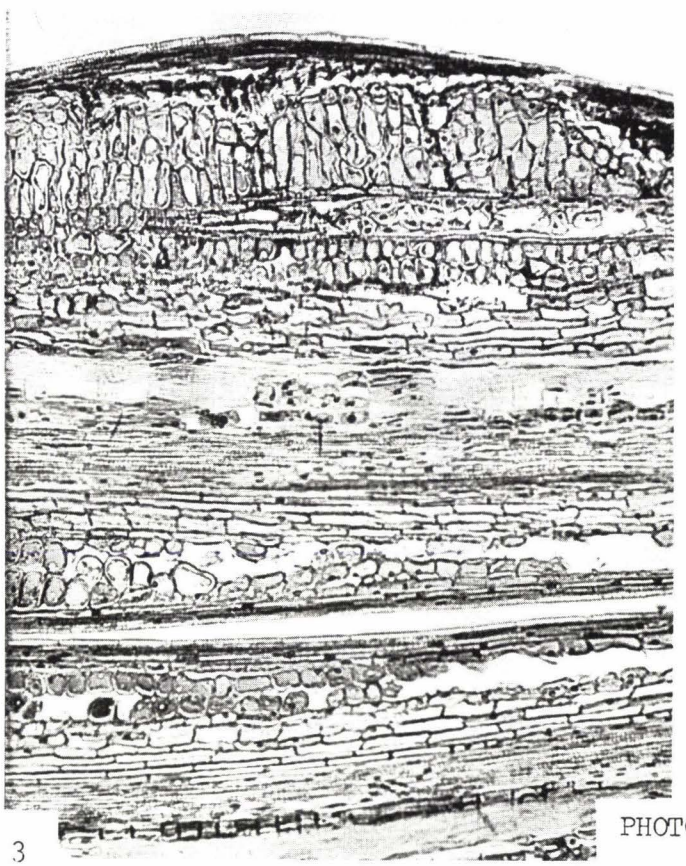

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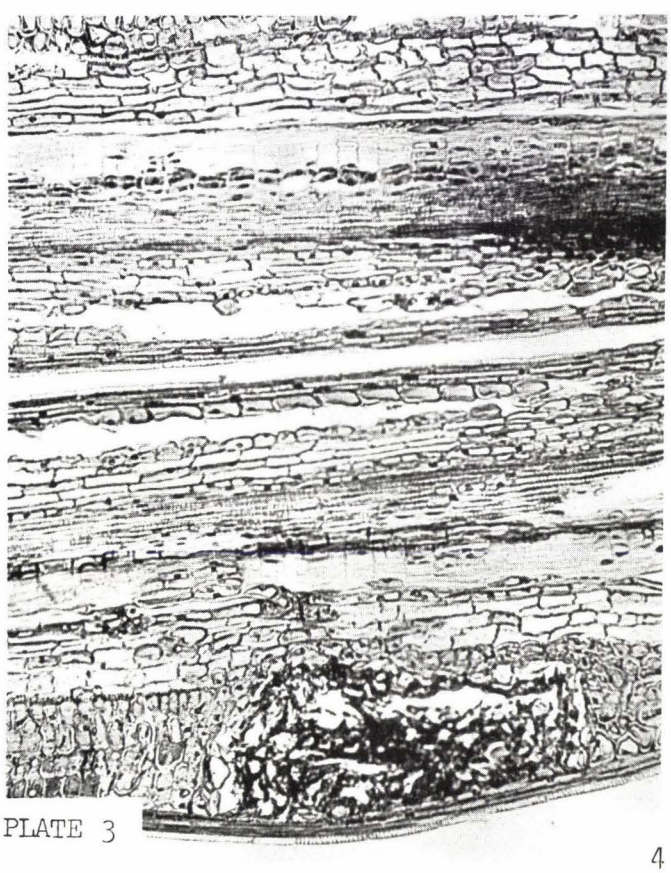

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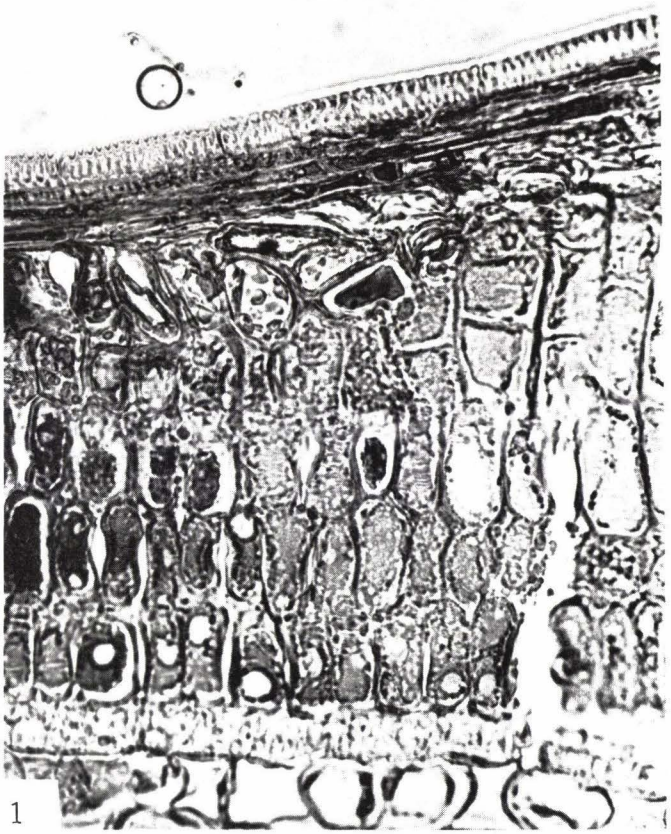

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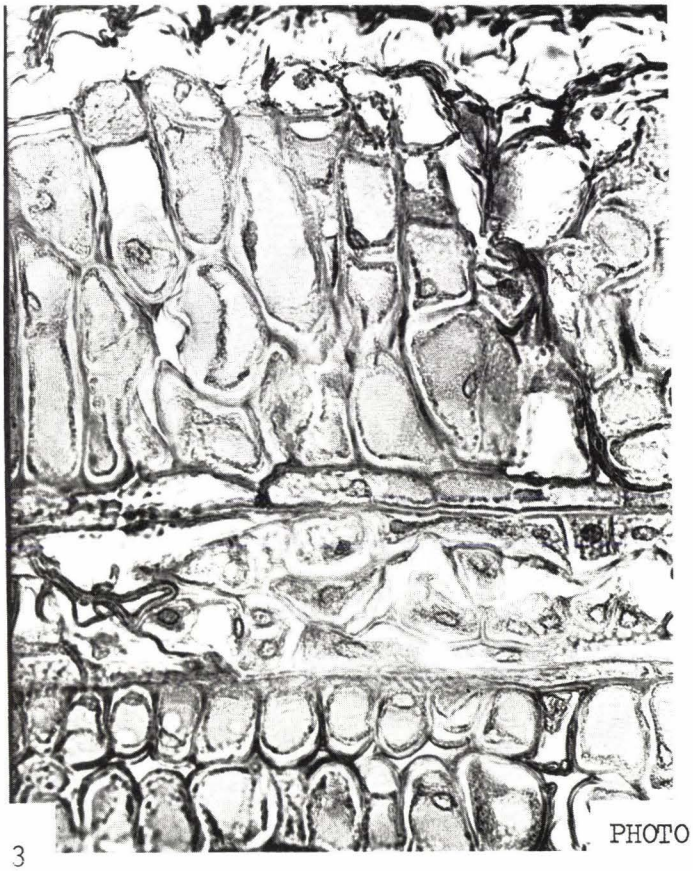

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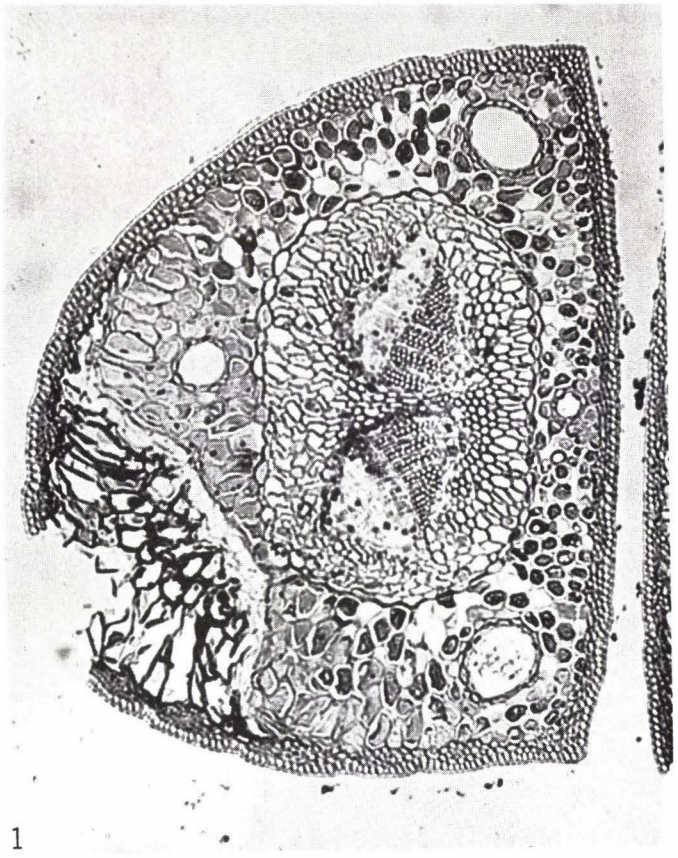

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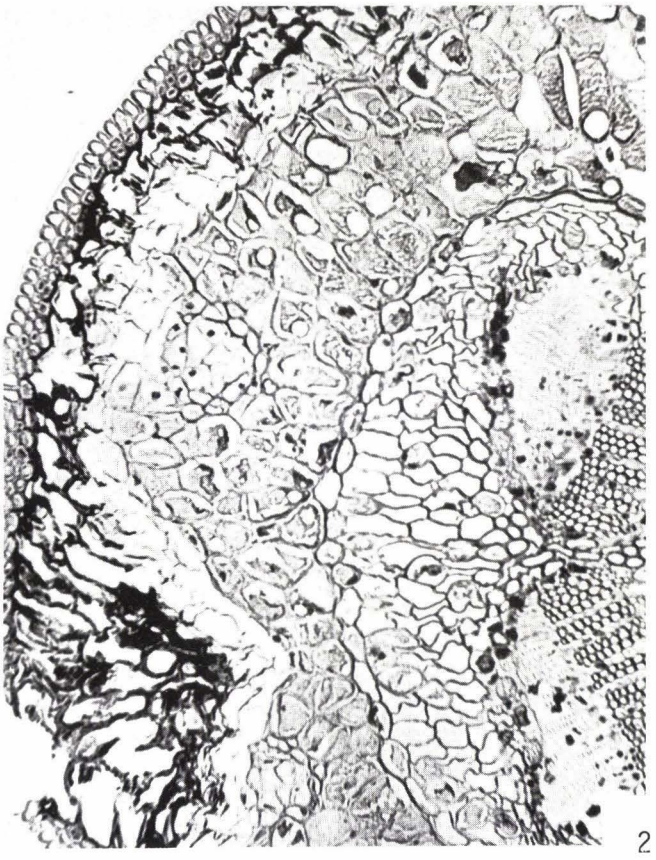

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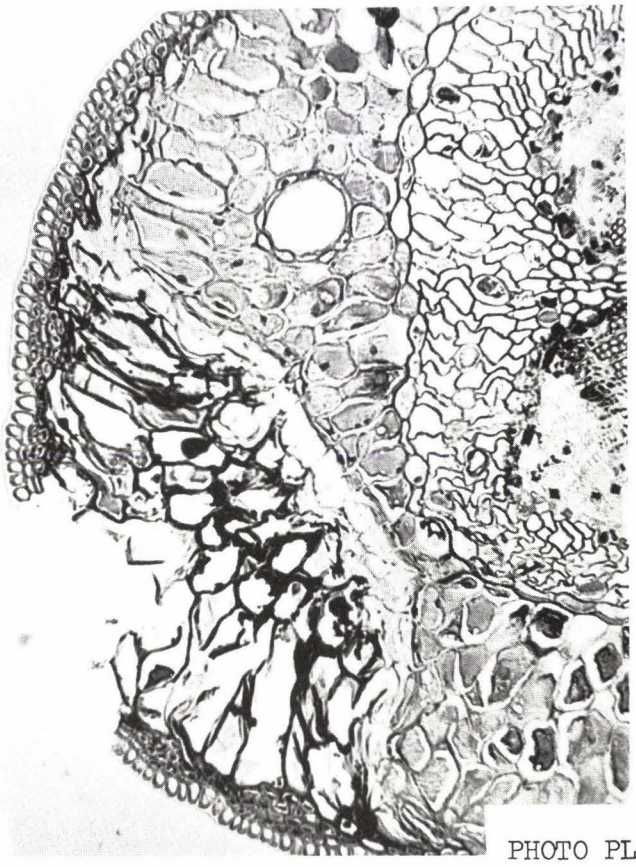

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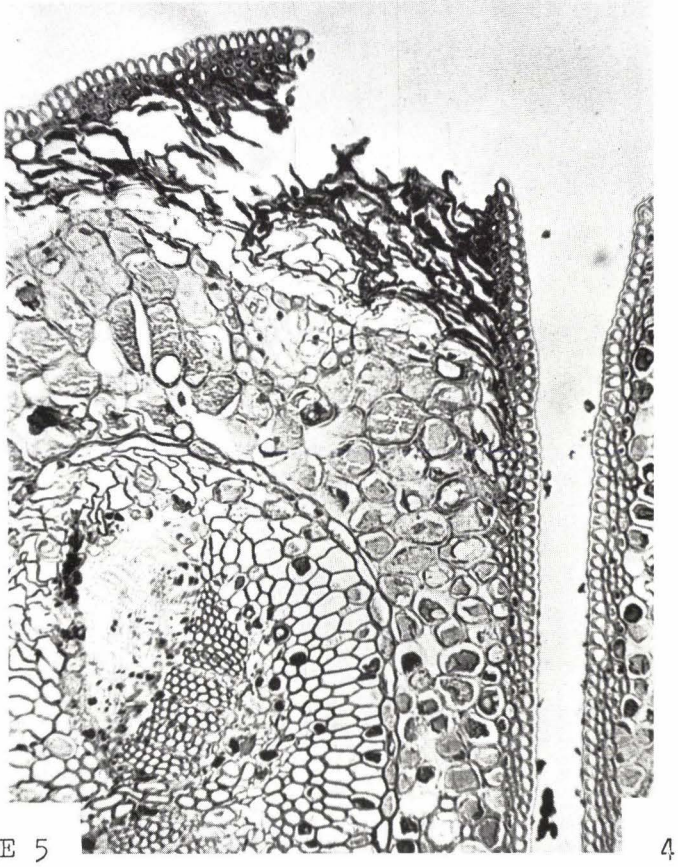

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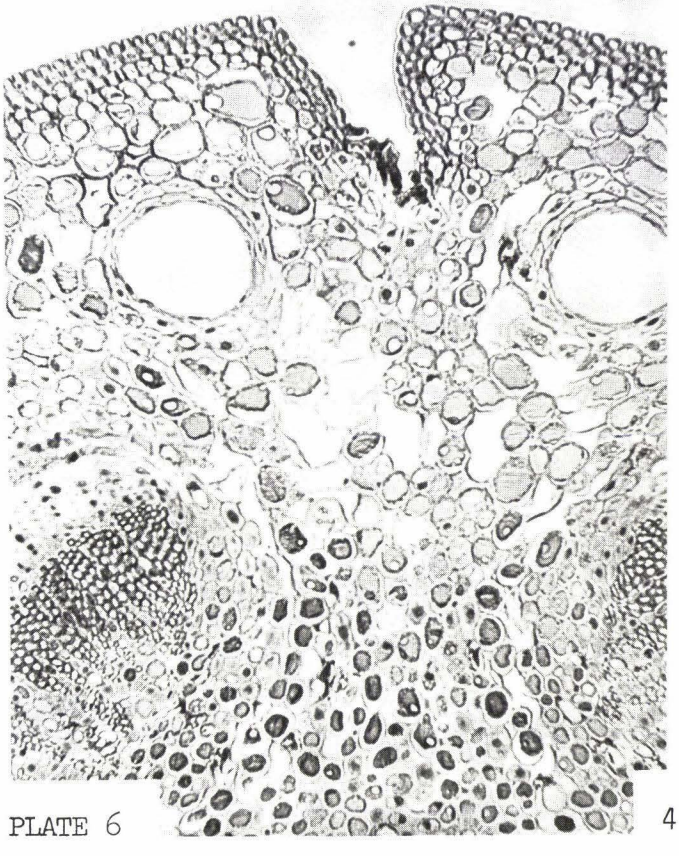

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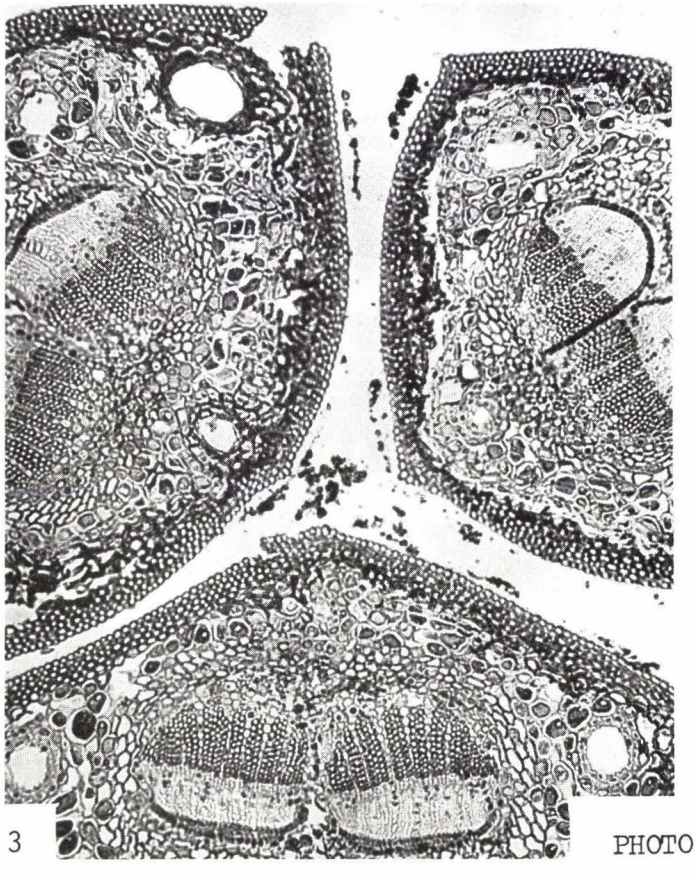

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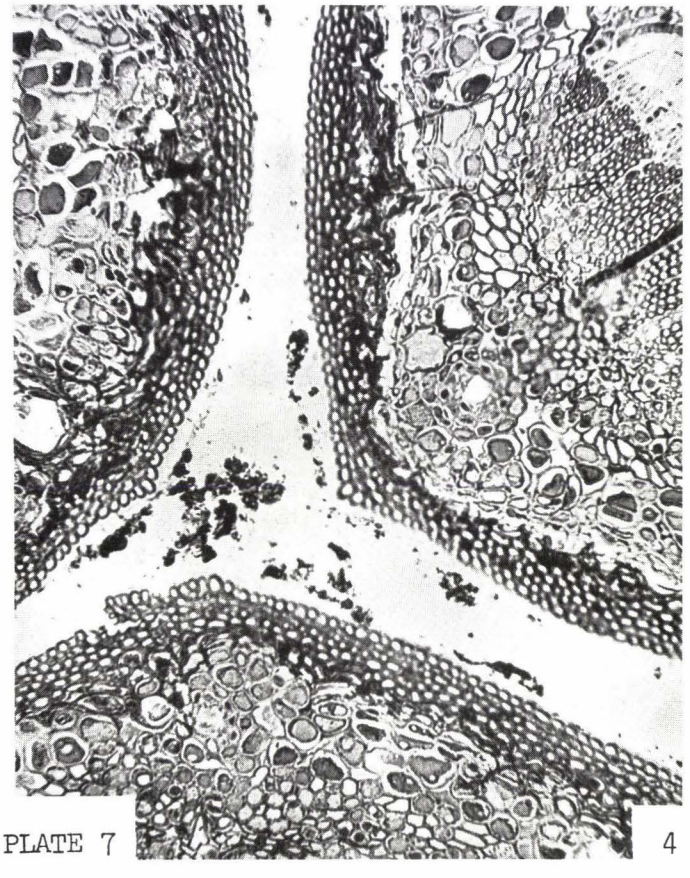

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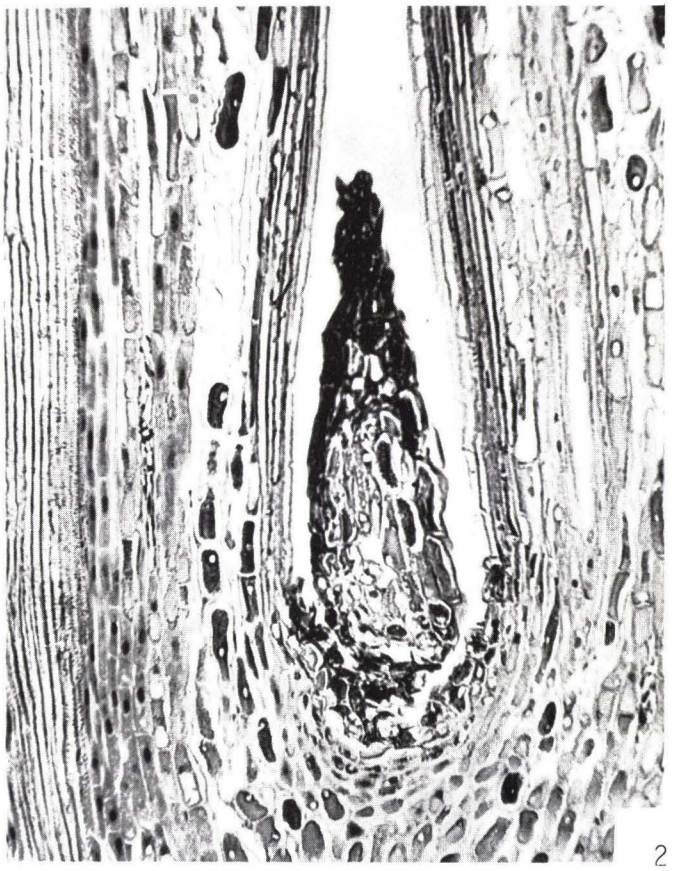

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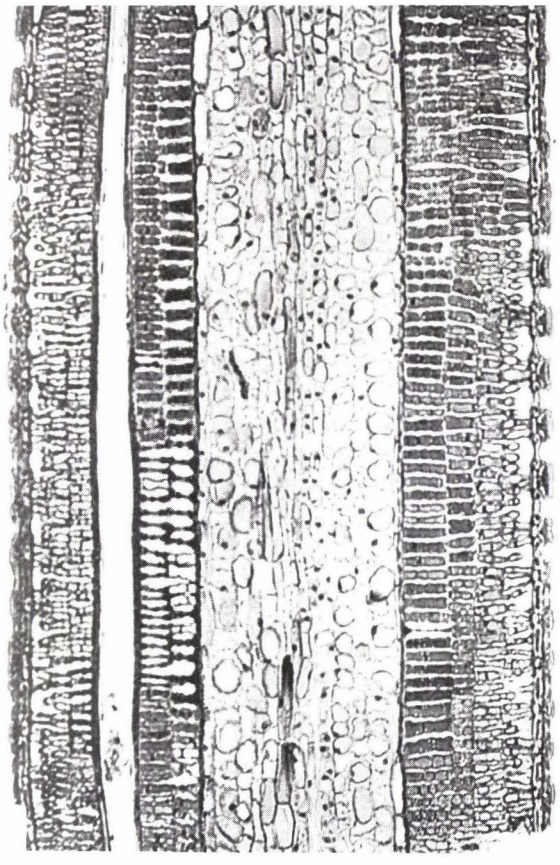

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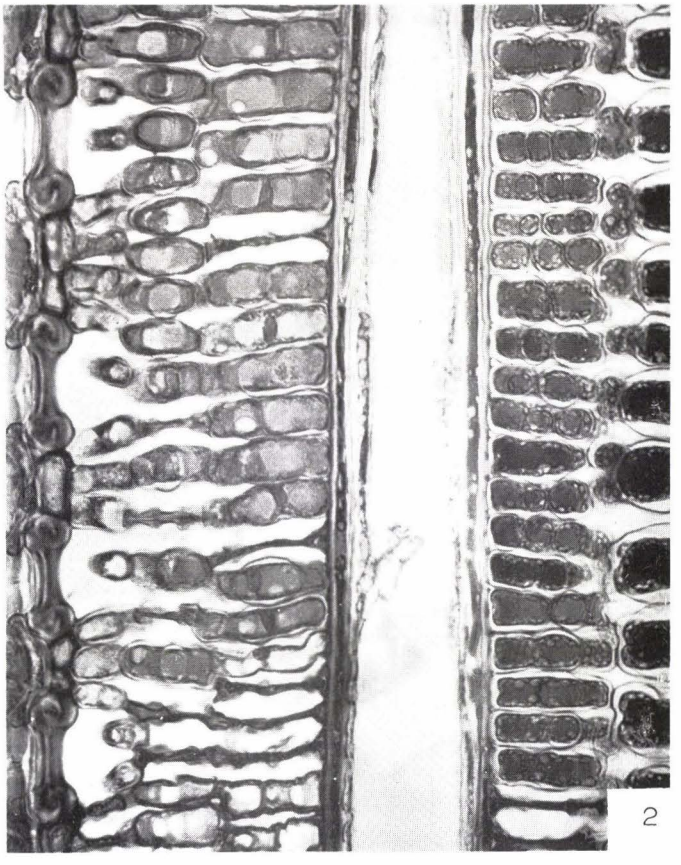

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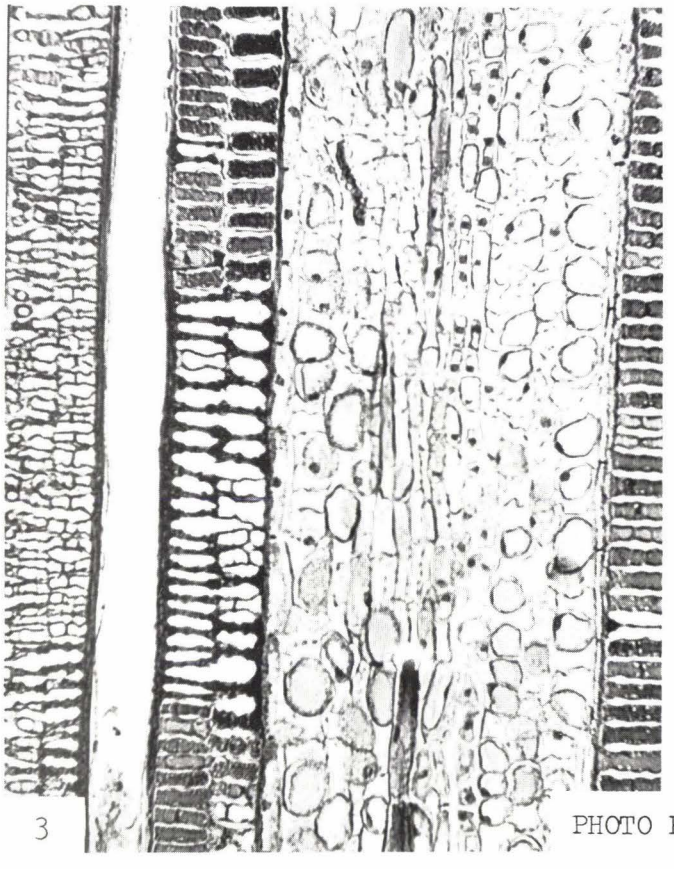

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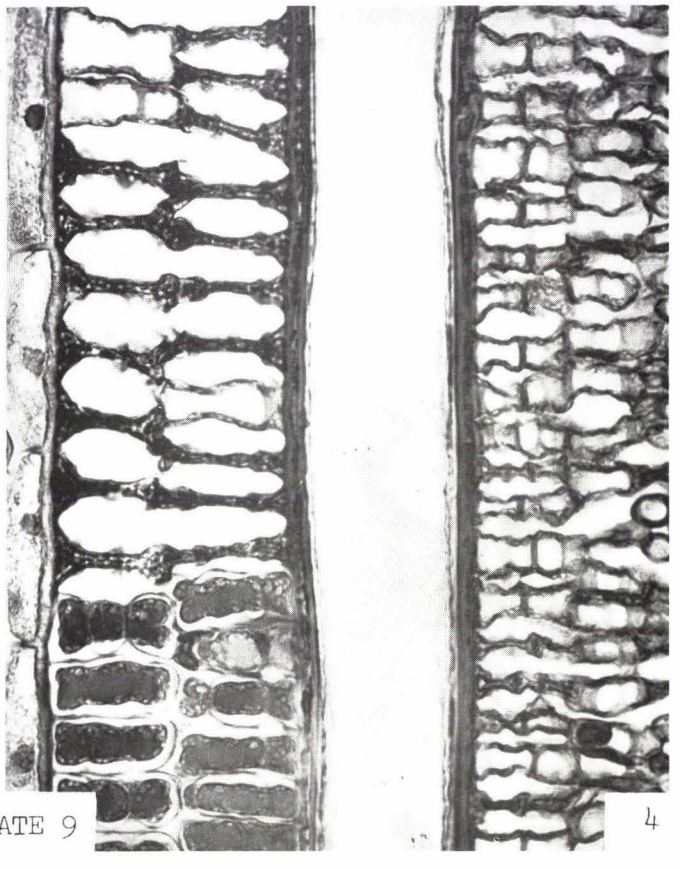

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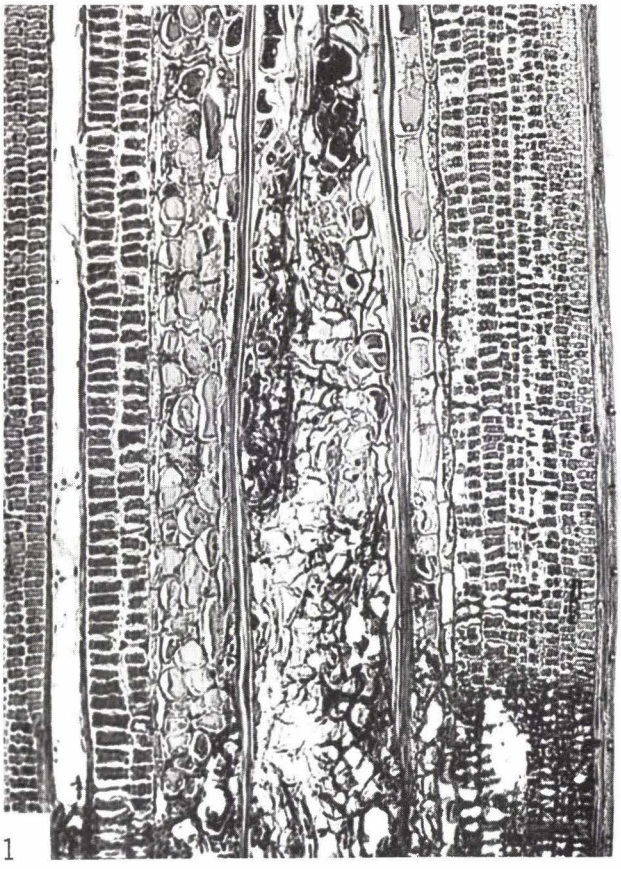

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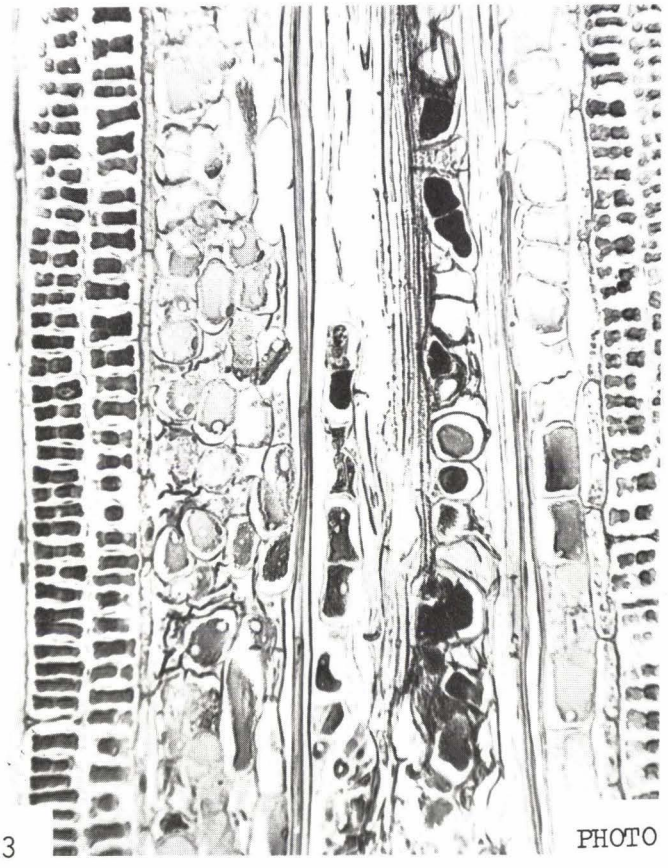

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PHOTO PLATE 10

APPENDIX I

Fluoride Analysis of Vegetation

The method of fluoride (F^-) analysis of vegetation employed in this study to obtain the results reported was developed in 1970 at the University of Montana Environmental Studies Laboratory. This method incorporated the Orion fluoride specific ion electrode as the fluoride sensor. It is precise and rapid, and the results of comparative studies using other techniques show very good agreement.

0.50 g. of dried, ground plant material was placed in a 35 ml. nickel crucible with 0.05 g. of low fluorine calcium oxide and slurried with distilled water. The slurry was first dried and then charred under infrared, transferred to a muffler furnace, and ashed overnight at 600° C. The crucibles were covered during ashing.

When the crucibles were cool, the ash was moistened with distilled water, dissolved in a minimum of 30 per cent perchloric acid, made to 100 ml. with 50 per cent TISAB, transferred to a plastic beaker, placed on a magnetic stirrer, and the electrodes inserted into the stirred solution. The solution was insulated from the heat of the stirrer with a half inch of sponge and the millivolt (MV) reading was recorded after the electrodes had equilibrated.

Immediately prior to sample analysis, the electrodes were calibrated with standard solutions of the following fluoride concentrations: 0.05, 0.10, 0.50, 1.0, 5.0, 10.0, and 19.0 ppm.

The preparation of the calibration curve and the calculation of the fluoride concentration of unknown samples is computerized.

Samples with F^- concentrations falling below the useful range of the calibration curve were treated by adding sufficient fluoride to bring them into the millivolt range. For most plant materials, 1 ml. of a 5.0 ppm F^- solution was sufficient. Reagent blanks were carried through the entire procedure with each series of samples.

APPENDIX II

Sulfur Analysis of Vegetation

The total sulfur (S) content of vegetation was determined by a combustion iodometric procedure employing a Leco induction furnace to generate SO_2 and titrating the SO_2 with potassium iodate (A.S.T.M. E30-47). An aliquot of dried, ground plant material was weighed into a crucible, tin and iron metal catalysts were added, and the crucible was placed into the furnace induction field. The sample was combusted in an oxygen atmosphere to generate SO_2 which was bubbled through a solution of iodine and starch. Sulfur dioxide generated in the furnace bleaches the solution of starch and free iodine by the following reaction:

$$SO_2 + I_2 + H_2O \rightarrow H_2SO_4 + 2HI$$

The blue color was maintained by titrating the starch solution with potassium iodate:

$$KIO_3 + 5KI + 6HCl \rightarrow 6KCl + 3I_2$$

The titration continued until SO_2 generation was completed, as evidenced by the maintenance of blue color in the starch solution without adding KIO_3 (15).

Recovery Studies

In order to determine recovery efficiency of the combustion iodometric method for the analysis of total sulfur in plant material, three separate experiments were performed. First, aliquots of potassium aluminum sulfate were analyzed (Table 2). Second, known amounts of thiourea (NH_2CSNH_2) were adsorbed onto cellulose to give varying concentrations of sulfur in cellulose, and these standards were then analyzed (Table 3). Finally, cellulose standards and plant samples were mixed to determine the effect of plant material on the recovery of sulfur from the standards (Table 4). Sample aliquots of 0.1 g. were used to obtain the data for Tables 3 and 4, since preliminary work had shown that such aliquots of plant material resulted in good combustion without violence and ready conversion to percent sulfur in the sample. The data in Table 4 show that the lowest recoveries were obtained

with the largest volume of plant material and the smallest volume of collulose-thiourea.

The average S content of Pinus foliage collected away from areas subjected to sulfurous air pollution has been previously reported. Katz and McCallum (11) report average total sulfur concentrations of .09 to .13 per cent. Thomas et al. (12) report average sulfur content in different year's foliage of conifers ranging from .10 to .11 per cent, and they indicate that organic S in conifers normally is about .1 per cent. The data of Kelley and Lambert (16) indicate that sulfate-sulfur in the foliage of Pinus radiata averages less than .025 per cent.

In view of the above, it appears that species of Pinus found away from sources of sulfurous air pollution may contain most of their sulfur as organic sulfur and possibly less than 250 ppm of their total sulfur as inorganic S. Therefore, the efficiency of recovery for the combustion iodometric method used in this study was based upon the results of recovery studies employing cellulose-thiourea standard and plant sample mixtures.

Because the lowest recoveries were obtained with the largest amount of plant material relative to the cellulose standard (Table 4), a graph was prepared (Figure 3) from which a given analysis of plant material could be increased by an amount of sulfur reflecting the low recovery. The recovery results of 2200 ppm S for a 2500 ppm concentration, and 700 ppm S for a 1000 ppm concentration were used to prepare Figure 3. Thus, if a given analysis of plant material resulted in a concentration of 1500 ppm S (X-axis, Figure 3), the result to be reported is 1800 ppm S (Y-axis, Figure 3).

Method of Sulfur Analysis

Weigh 0.10 g. of dried, ground plant material into a combustion crucible, add 1 scoop of iron and 2 scoops of tin metal. Add starch and HCl to the

titration vessel, and titrate KIO_3 until the endpoint blue color is reached. Record the burette reading. Cover the crucible and place it in the induction furnace. Titrate with KIO_3 to keep the endpoint blue color until the solution is no longer bleached. Record the resultant burette reading. Determine the total sulfur content by use of Equations I and II below. Report the results as ppm S.

Equation I: Per cent S = (Final Burette Reading - Initial Burette Reading) - Blank

Equation II: Ppm S = (Per cent S) (10^4) + Increase from Figure 3

TABLE 2

RESULTS OF ANALYSES OF POTASSIUM ALUMINUM SULFATE ($KAl(SO_4)_2$) AS THE SOURCE OF SULFUR FOR SO_2 GENERATION

Grams S x 10^{-5} Added	Grams S x 10^{-5} Recovered
46.5	43
46.5	43
46.5	47
36.4	33
30	29
30.3	29
24.8	22
24.2	21
24.6	13
17.8	16
18.2	16
13.5	13
10.7	11
9.4	9
10	9

TABLE 3

RESULTS OF ANALYSES OF SYNTHETIC PLANT STANDARDS PREPARED BY ADSORBING THIOUREA ON PURE CELLULOSE

Ppm S Concentration in Cellulose-Thiourea	Ppm S Concentration in Cellulose-Thiourea Recovered by Analysis	Average
10000	9200	9200
5000	4700	4666
	4600	
	4700	
3000	2800	2866
	2800	
	3000	
2500	2300	2333
	2400	
	2300	
1500	1500	1433
	1500	
	1300	
1000	900	933
	1000	
	900	
500	500	533
	500	
	600	
0	0	0
	0	
	0	

TABLE 4

RESULTS OF SULFUR RECOVERY FROM SYNTHETIC PLANT STANDARDS
PONDEROSA PINE MIXTURES

Ppm S in Cellulose	Weight (g) Cellulose	Weight (g) P. Ponderosa	Ppm S Recovered	Average
2500	.025	.075	2000	2200
"	.025	.075	2400	
2500	.05	.05	2700	2433
"	.05	.05	2500	
"	.05	.05	2100	
1500	.05	.05	1500	1366
"	.05	.05	1400	
"	.05	.05	1200	
1000	.01	.09	800	700
"	.01	.09	700	
"	.01	.09	600	
500	.05	.05	500	500
"	.05	.05	500	

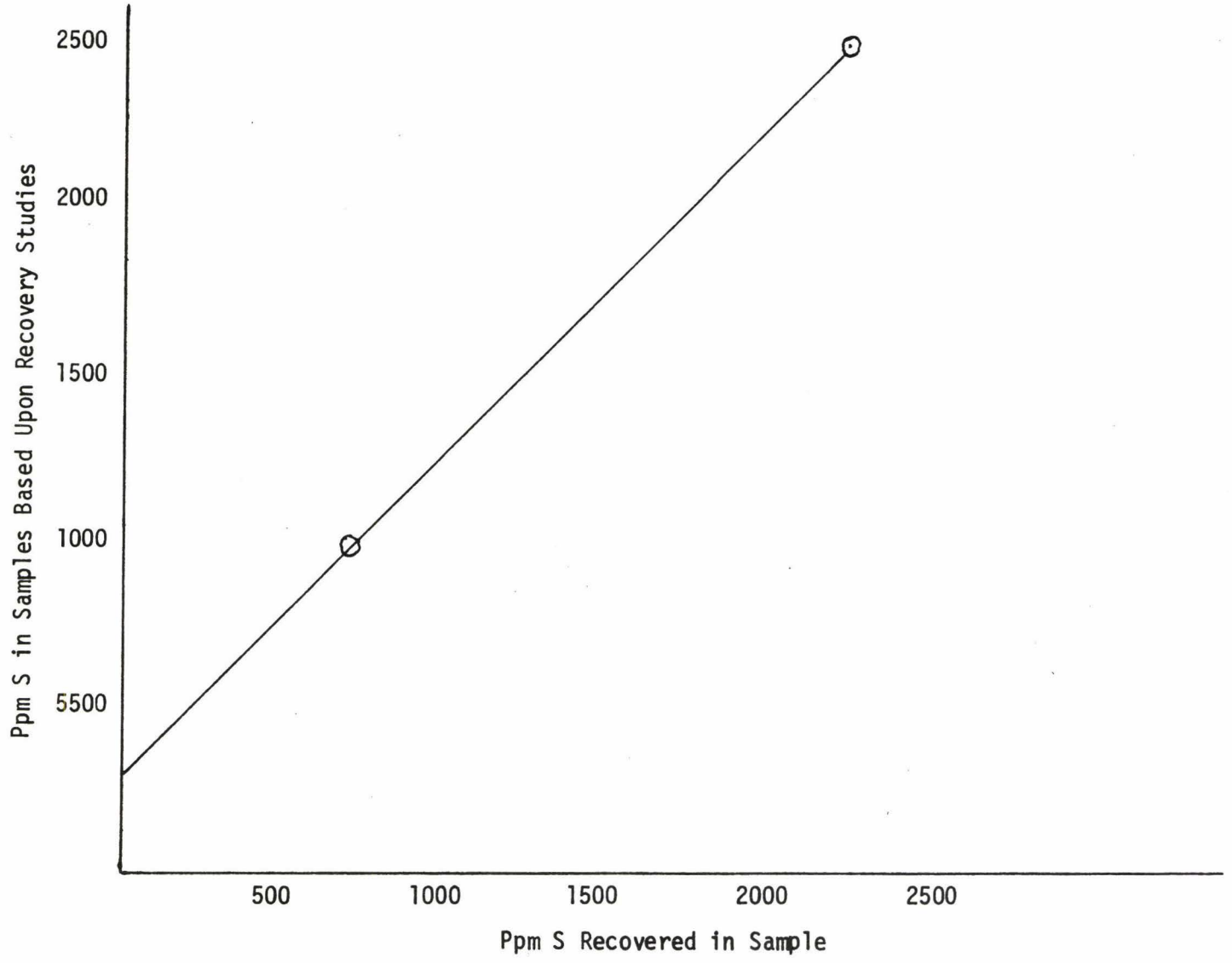
2500
2000
1500
1000
5500
Ppm S in Samples Based Upon Recovery Studies
500
1000
1500
2000
2500
Ppm S Recovered in Sample

FIGURE 3

APPENDIX III

APPENDIX III

Chlorophyll Analysis
Colstrip--1975

A. Collection and Storage

1. Collect 4 branches from the upper crown and 4 more from the lower crown of the plot tree FACING THE DIRECTION OF COLSTRIP. (Always sample the same side of the tree.) Each branch should include 5 internodes of growth (1975 to 1971 foliage). If the branch does not include growth to 1971, sample another branch or two if needed.
2. Strip 5 needles per year at random from each branch, and place in whirl bags with appropriate labels (there will be 20 needles in each sample).
   a. Close bag tightly and place upright on ice in a cooler. Place cooler in the shade.
   b. Keep all samples in the dark as much as possible. Light destroys chlorophyll.
3. Place cooler in refrigeration immediately upon returning to lab.
   a. As soon as possible freeze all samples in the dark.
   b. The frozen samples may be stored, if they are all stored for the same length of time (refer to Appendix VII and text).

B. Preparation

1. Keep unprepared samples on ice in cooler out of direct sunlight while working on preparation.
2. Discard necrotic needle material from the sample--chlorophyll cannot be analyzed on necrotic tissue.
3. With a razor blade, cut the central portion (middle third of the needle) into 2-3 mm lengths.

4. Mix the cuttings thoroughly and weigh out 0.075 g of the chopped needles.
5. Place the weighed portion into small labeled vials, add 3-5 ml of 100% spectrophotometric grade methanol, and cap vials tightly.
6. Throughout this entire process keep the samples covered as much as possible and out of direct sunlight.

C. Extraction

1. Cover vials with aluminum foil to keep light out and store in a dark place for 24 hours.
2. Decant green methanol into another vial leaving needles behind and label.
3. Add an additional 3-5 ml of methanol to the vial containing the chopped tissue, and place both extracts in a dark, cool place for an additional 24 hours.
4. Decant the first extract back into the second extraction. By now the needle material should be white or yellow, free of all chlorophyll. If they are not, add an additional 3-5 ml of methanol and extract for an additional 24 hours. Avoid the third extraction if possible.
5. Cover, label, and place in freezer. These samples may be stored an additional three weeks at this stage.

D. Analyses (Using Spectronic 20)

1. Allow extractions to warm to room temperature if they have been frozen.
2. Bring the green-colored extract to 10.0 ml in a volumetric flask by adding methanol via a small glass funnel. If the needles are extracted three times, there may be more than 10 ml of extract. In this case, bring the extract to 15 ml.

3. Decant the extract into a square cuvette, filling the cuvette approximately three quarters full. Pour the extract into the corner of the cuvette to prevent spilling. Read absorbance at 650 and 665 ml. Rinse cuvette and volumetric flask with methanol and invert to drain after each sample reading.

4. Calibrating the Spectronic 20:

   a. Turn the machine on and warm up for 45-60 minutes.

   b. Adjust the wavelength dial to 650 mu.

   c. Adjust the left-hand knob until the meter needle is zeroed on the left side of the scale with the sample chamber closed and empty (no cuvette inside).

   d. Fill a blank cuvette three quarters full with spectrophotometric grade methanol, and place in the sample chamber; close lid. With the blank in place, turn the right-hand knob until the right side of the scale is also zeroed.

5. Reading absorbance (or optical density, O.D.):

   a. Remove the blank from the sample chamber but save it to check the calibration every tenth sample.

   b. Place the sample from step no. 3 above into the sample chamber, close the lid, and read absorbance off the dial. Record on data sheet.

   c. Decant the sample back into the original vial. Run the remaining samples at 650 mu as outlined above.

   d. Recalibrate the machine as above for 665 mu. Rezero the needle on the left- and right-hand side of the scale.

   e. Run all samples of chlorophyll at 665 mu, read absorbance, and record on data sheet.

E. Calculations

1. Convert the optical density readings at 650 and 665 mu to mg/l of chlorophyll by the following formulas:

   a. Correction to 1 cm light path:

      Let M = 0.0 + 0.87 * X

      Let N = 0.01 + 0.85 * Y

      X = O.D. at 650 mu

      Y = O.D. at 665 mu

   b. Computation of Chlorophyll A, B, and Total Chlorophyll A + B:

      A = 16.5 * N - 8.3 * M

      B = 33.8 * M - 12.5 * N

      Total A + B = 25.5 * M + 4.0 * N

Notes: All chlorophyll samples to be used for comparison must be collected as near to the same date as possible and within the same weather conditions (e.g., drought, heavy rain, snow). All such samples should also be extracted at the same time after they have been collected.

Fresh needles may be stored for equal periods of time by freezing, and extractions may also be stored for three weeks by freezing. But be cautious when storing samples in some "frost-free" freezers. They are notorious for dehydrating the material placed in them. If methanol evaporates from the extractions, the concentrations of chlorophyll will increase and give a false reading.

When preparing the fresh needle material, add a duplicate of every tenth sample to check your technique and the variability of the samples.

While running the samples through the Spectronic 20, always use one cuvette for a blank and one for the samples. Avoid putting a wet cuvette in the machine--clean and dry the cuvette thoroughly before

placing sample in the machine. DO NOT TOUCH the lower half of the cuvette with your fingers or other oil sources. Mark one side of the cuvette near the top, and always put the cuvette into the machine the same way each time.

This method is from: Holden, M. 1965. Chlorophylls in Chemistry and Biochemistry of Plant Pigments. T.W. Goodwin, ed., Academic Press, New York. pp. 461-488, with additions by Bill Hammer and Pat Meinhardt.

APPENDIX IV

SUMMARY OF TREE DATA

Form _____

Plot No. _____ Date of collection _____ Collector _____ Weather conditions _____

Tree No. _____ Reproductive potential _____

Species _____

Percent pollen germ $\bar{X}$	Percent pollen germ $S\bar{x}$	Percent sound seed $\bar{X}$	Percent sound seed $S\bar{x}$

Crown position	Year of foliage origin	Age of foliage months	Percent needle retention $\bar{X}$	Percent needle retention $S\bar{x}$	Weight: Wet $\bar{X}$	Weight: Wet $S\bar{x}$	Weight: Dry $\bar{X}$	Weight: Dry % H_2O $\bar{X}$	Weight: Dry % H_2O $S\bar{x}$	Length $\bar{X}$	Length $S\bar{x}$	Area $\bar{X}$	Area $S\bar{x}$	Needle pathology, percent: Basal necrosis	Tip burn	Mottled	Healthy	Basal scale	Basal midge	Pine needle scale	Defoliator	Needle miner	Weevil	Other	Tot. necrosis
Upper																									
Lower																									

Crown position	Year of foliage origin	Chemical analysis: Total sulfur	Chemical analysis: Fluoride	Chlorophyll	Trace metals	Results of needle autopsy	Remarks
Upper							
Lower							

APPENDIX IV

Form _____

SUMMARY OF TREE DATA

Plot No. _____ Date of collection _____ Collector _____ Weather conditions _____

Tree No. _____ Reproductive potential _____

Species _____

Percent pollen germ $\bar{X}$	Percent pollen germ $S\bar{x}$	Percent sound seed $\bar{X}$	Percent sound seed $S\bar{x}$

Crown position	Year of foliage origin	Age of foliage months	Percent needle retention $\bar{X}$	Percent needle retention $S\bar{x}$	Weight: Wet $\bar{X}$	Weight: Wet $S\bar{x}$	Weight: Dry $\bar{X}$	Weight: Dry % H_2O $\bar{X}$	Weight: Dry % H_2O $S\bar{x}$	Length $\bar{X}$	Length $S\bar{x}$	Area $\bar{X}$	Area $S\bar{x}$	Needle pathology, percent: Basal necrosis	Tip burn	Mottled	Healthy	Basal scale	Basal midge	Pine needle scale	Defoliator	Needle miner	Weevil	Other	Tot. necrosis
Upper																									
Lower																									

Crown position	Year of foliage origin	Chemical analysis: Total sulfur	Chemical analysis: Fluoride	Chlorophyll	Trace metals	Results of needle autopsy	Remarks
Upper							
Lower							

APPENDIX V

APPENDIX V

COMMON AND SCIENTIFIC NAMES OF PLANT SPECIES

Common Name	Scientific Name
Big sage	*Artemisia tridentata*
Silver sage	*A. cana*
Prairie sage	*A. ludoviciana*
Fringed sage	*A. frigida*
Unknown sage	*A. sp.*
Yucca	*Yucca glauca*
Broom snakeweed	*Gutierrezia sarothrae*
Skunkbush	*Rhus trilobata*
Serviceberry	*Amelanchier alnifolia*
Chokecherry	*Prunus virginiana*
Dogbane	*Apocynum sp.*
Hazelnut	*Corylus sp.*
Buckbrush	*Ceonothus sp.*
Cinquefoil	*Potentilla sp.*
Kinnikinnick	*Arctostaphylos sp.*
Arrowleaf balsamroot	*Balsamorhiza sagitatta*
Sweet clover	*Melilotus sp.*
Lupine	*Lupinus sp.*
Scurf pea	*Psoralia sp.*
Vetch	*Vicia sp.*
Idaho fescue	*Festuca idahoensis*
Bluebunch wheatgrass	*Agropyron spicatum*
Crested wheatgrass	*A. cristatum*
Little bluestem	*Andropogon scoparius*
Red three-awn	*Aristida longiseta*
Needle-and-thread	*Stipa comata*
Oak	*Quercus sp.*
Quaking aspen	*Populus tremuloides*
Ponderosa pine	*Pinus ponderosa*

APPENDIX VI

APPENDIX VI

DESCRIPTIVE STATISTICS FOR THE INDICATED PARAMETERS FOR THE NINE CATEGORIES OF TREE AGE AND CROWN POSITION
CNF PLOTS 1-17, 1973 YEARS FOLIAGE ONLY

ALL YOUNGER TREES, ALL CROWN POSITIONS

Parameter	N	$\bar{X}$	95% Confidence Interval	Median	σ	$s_{\bar{x}}$
ppm F	155	1.45	$1.33 \leq \mu \leq 1.56$	1.30	.74	.05
ppm S	155	483.00	$461.00 \leq \mu \leq 504.00$	500.00	134.00	10.08
% Needle retention	160	86.30	$84.10 \leq \mu \leq 88.40$	91.00	13.70	1.08
% Healthy needles	160	54.90	$51.40 \leq \mu \leq 58.30$	56.00	22.30	1.76
% Tip burn	160	4.80	$2.60 \leq \mu \leq 7.00$	0.00	14.00	1.10
% Basal necrosis	160	2.43	$1.90 \leq \mu \leq 2.90$	2.00	3.14	.24
% Basal scale	160	8.80	$6.70 \leq \mu \leq 10.80$	3.00	13.00	1.03
Needle length (mm)	160	128.00	$125.60 \leq \mu \leq 131.70$	127.60	19.40	1.53
Needle x sectional area (mm^2)	160	2.19	$2.09 \leq \mu \leq 2.29$	2.12	.63	.05
Total a+b chlorophyll	149	1.015	$.980 \leq \mu \leq 1.049$	1.008	.212	.017
% Mottled needles	160	7.0	$5.25 \leq \mu \leq 8.90$	1.00	11.68	.92
% Needle necrosis	160	8.0	$6.58 \leq \mu \leq 9.42$	5.00	9.08	.71
% Water	137	49.6	$48.96 \leq \mu \leq 50.25$	50.00	3.83	.32
% Weevil	160	11.4	$9.65 \leq \mu \leq 13.24$	8.50	11.48	.90
% Pine needle scale	160	.56	$-.27 \leq \mu \leq 1.39$	.00	5.34	.42
% Defoliator	160	3.9	$3.24 \leq \mu \leq 4.69$	2.50	4.65	.36
% Other pathology	160	11.1	$8.91 \leq \mu \leq 13.45$	5.00	14.53	1.14

APPENDIX VI
(cont.)

ALL CROWN POSITIONS, OLDER TREES
1973 YEARS FOLIAGE

Parameter	N	$\bar{X}$	95% Confidence Interval	Median	σ	$s_{\bar{x}}$
ppm F	152	1.43	$1.32 \leq \mu \leq 1.55$	1.40	.72	.05
ppm S	152	488.00	$469.00 \leq \mu \leq 507.00$	500.00	116.00	9.48
% Needle retention	160	80.90	$78.40 \leq \mu \leq 83.50$	84.80	16.20	1.28
% Healthy needles	160	54.70	$51.20 \leq \mu \leq 58.10$	52.50	22.20	1.75
% Tip burn	159	2.30	$1.32 \leq \mu \leq 3.28$	0.00	6.25	.49
% Basal necrosis	160	2.40	$1.93 \leq \mu \leq 2.99$	1.50	3.88	.26
% Basal scale	160	8.50	$6.60 \leq \mu \leq 10.40$	4.00	12.24	.96
Needle length (mm)	160	128.00	$124.90 \leq \mu \leq 131.10$	129.00	19.70	1.55
Needle x sectional area (mm^2)	160	2.28	$2.18 \leq \mu \leq 2.38$	2.23	.64	.05
Total a+b chlorophyll	153	1.018	$.988 \leq \mu \leq 1.048$	1.010	.186	.015
% Mottled needles	160	8.0	$5.87 \leq \mu \leq 10.27$	2.00	14.06	1.11
% Needle necrosis	160	7.0	$5.89 \leq \mu \leq 8.16$	4.00	7.29	.57
% Water	134	48.8	$47.72 \leq \mu \leq 49.92$	48.8	6.44	.55
% Weevil	160	12.4	$10.38 \leq \mu \leq 14.42$	8.00	12.91	1.02
% Pine needle scale	159	.20	$-.005 \leq \mu \leq .40$	0.00	1.32	.10
% Defoliator	160	4.3	$3.42 \leq \mu \leq 5.25$	2.00	5.86	.46
% Other pathology	160	10.8	$8.99 \leq \mu \leq 12.61$	7.00	11.59	.91

APPENDIX VI
(cont.)

ALL TREES, UPPER CROWN POSITIONS
1973 YEARS FOLIAGE

Parameter	N	$\bar{X}$	95% Confidence Interval	Median	σ	$s_{\bar{x}}$
ppm F	154	1.41	$1.29 \leq \mu \leq 1.52$	1.30	.73	.05
ppm S	154	480.00	$459.00 \leq \mu \leq 500.00$	500.00	127.00	10.30
% Needle retention	160	88.50	$86.70 \leq \mu \leq 90.30$	93.00	11.50	.91
% Healthy needles	160	54.00	$50.40 \leq \mu \leq 57.70$	53.00	23.20	1.84
% Tip burn	159	3.50	$1.92 \leq \mu \leq 5.10$	0.00	10.13	.80
% Basal necrosis	160	2.10	$1.70 \leq \mu \leq 2.60$	1.00	2.87	.22
% Basal scale	160	8.60	$6.60 \leq \mu \leq 10.70$	3.00	13.10	1.04
Needle length (mm)	160	133.10	$130.00 \leq \mu \leq 136.20$	133.40	19.80	1.57
Needle x sectional area (mm^2)	160	2.39	$2.28 \leq \mu \leq 2.50$	2.31	.70	.05
Total a+b chlorophyll	160	1.012	$.981 \leq \mu \leq 1.043$	1.009	.191	.015
% Mottled needles	160	8.8	$6.58 \leq \mu \leq 11.13$	2.0	14.56	1.15
% Needle necrosis	160	7.7	$6.43 \leq \mu \leq 8.99$	5.0	8.19	.64
% Water	137	49.4	$48.33 \leq \mu \leq 50.46$	49.8	6.30	.53
% Weevil	160	11.0	$9.37 \leq \mu \leq 12.77$	8.0	10.91	.86
% Pine needle scale	159	.32	$-.01 \leq \mu \leq .66$	0.0	2.17	.17
% Defoliator	160	3.7	$3.07 \leq \mu \leq 4.51$	2.0	4.60	.36
% Other pathology	160	12.9	$10.75 \leq \mu \leq 15.19$	8.0	14.23	1.12

APPENDIX VI
(cont.)

ALL TREES, LOWER CROWN POSITIONS
1973 YEARS FOLIAGE

Parameter	N	$\bar{X}$	95% Confidence Interval	Median	σ	$s_{\bar{x}}$
ppm F	153	1.47	$1.36 \leq \mu \leq 1.59$	1.40	.72	.05
ppm S	153	491.00	$471.00 \leq \mu \leq 511.00$	500.00	124.00	10.00
% Needle retention	160	78.70	$76.10 \leq \mu \leq 81.40$	83.40	16.80	1.33
% Healthy needles	160	55.50	$52.20 \leq \mu \leq 58.80$	54.50	21.20	1.67
% Tip burn	160	3.65	$1.83 \leq \mu \leq 5.47$	0.00	11.67	.92
% Basal necrosis	160	2.70	$2.10 \leq \mu \leq 3.20$	2.00	3.60	.28
% Basal scale	160	8.60	$6.70 \leq \mu \leq 10.50$	3.00	12.10	.95
Needle length (mm)	160	123.50	$120.70 \leq \mu \leq 126.30$	123.10	18.00	1.42
Needle x sectional area (mm^2)	160	2.08	$2.00 \leq \mu \leq 2.16$	2.04	.52	.04
Total a+b chlorophyll	150	1.021	$.987 \leq \mu \leq 1.054$	1.016	.208	.016
% Mottled needles	160	6.3	$4.59 \leq \mu \leq 8.00$	1.00	10.91	.86
% Needle necrosis	160	7.3	$6.01 \leq \mu \leq 8.61$	4.5	8.31	.65
% Water	134	49.0	$48.35 \leq \mu \leq 49.73$	49.3	4.02	.34
% Weevil	160	12.7	$10.69 \leq \mu \leq 14.86$	8.0	13.36	1.05
% Pine needle scale	160	.43	$-.35 \leq \mu \leq 1.22$	0.0	5.06	.40
% Defoliator	160	4.5	$3.60 \leq \mu \leq 5.43$	3.0	5.88	.46
% Other pathology	160	9.0	$7.20 \leq \mu \leq 10.83$	4.5	11.63	.91

APPENDIX VI
(cont.)

YOUNGER TREES, UPPER CROWN POSITIONS
1973 YEARS FOLIAGE

Parameter	N	$\bar{X}$	95% Confidence Interval	Median	σ	$s_{\bar{x}}$
ppm F	78	1.36	$1.19 \leq \mu \leq 1.53$	1.30	.74	.08
ppm S	78	476.00	$443.00 \leq \mu \leq 509.00$	450.00	147.00	16.60
% Needle retention	80	91.30	$89.30 \leq \mu \leq 93.30$	95.00	9.00	1.01
% Healthy needles	80	54.60	$49.60 \leq \mu \leq 59.60$	55.50	22.40	2.51
% Tip burn	80	4.70	$1.90 \leq \mu \leq 7.50$	0.00	12.50	1.40
% Basal necrosis	80	2.00	$1.30 \leq \mu \leq 2.70$	1.00	3.09	.34
% Basal scale	80	8.60	$5.50 \leq \mu \leq 11.60$	3.00	13.60	1.52
Needle length (mm)	80	134.80	$130.40 \leq \mu \leq 139.30$	134.60	20.10	2.25
Needle x sectional area (mm^2)	80	2.38	$2.22 \leq \mu \leq 2.53$	2.31	.70	.07
Total a+b chlorophyll	76	1.009	$.962 \leq \mu \leq 1.057$	.971	.209	.024
% Mottled needles	80	7.9	$5.08 \leq \mu \leq 10.71$	1.0	12.63	1.41
% Needle necrosis	80	8.2	$6.25 \leq \mu \leq 10.26$	6.0	9.01	1.00
% Water	70	49.6	$48.59 \leq \mu \leq 50.62$	49.9	4.25	.50
% Weevil	80	10.4	$8.26 \leq \mu \leq 12.65$	9.0	9.87	1.10
% Pine needle scale	80	.31	$-.23 \leq \mu \leq .86$	0.0	2.46	.27
% Defoliator	80	3.8	$2.81 \leq \mu \leq 4.88$	2.0	4.65	.52
% Other pathology	80	14.0	$10.42 \leq \mu \leq 17.57$	7.5	16.06	1.79

APPENDIX VI
(cont.)

UPPER CROWN POSITIONS, OLDER TREES
1973 YEARS FOLIAGE

Parameter	N	$\bar{X}$	95% Confidence Interval	Median	σ	$s_{\bar{x}}$
ppm F	76	1.45	$1.28 \leq \mu \leq 1.62$	1.35	.72	.08
ppm S	76	484.00	$460.00 \leq \mu \leq 508.00$	500.00	105.00	12.09
% Needle retention	80	85.60	$82.70 \leq \mu \leq 88.50$	88.60	12.90	1.44
% Healthy needles	80	53.50	$48.10 \leq \mu \leq 58.90$	52.00	24.20	2.70
% Tip burn	79	2.20	$.74 \leq \mu \leq 3.70$	0.00	6.70	.75
% Basal necrosis	79	2.20	$1.60 \leq \mu \leq 2.80$	1.50	2.64	.29
% Basal scale	80	8.70	$5.80 \leq \mu \leq 11.50$	4.50	12.70	1.42
Needle length (mm)	80	131.40	$127.00 \leq \mu \leq 135.70$	131.10	19.50	2.18
Needle x sectional area (mm^2)	80	2.41	$2.25 \leq \mu \leq 2.57$	2.33	.71	.08
Total a+b chlorophyll	76	1.015	$.975 \leq \mu \leq 1.054$	1.011	.172	.019
% Mottled needles	80	9.8	$6.18 \leq \mu \leq 13.44$	2.0	16.31	1.82
% Needle necrosis	80	7.1	$5.55 \leq \mu \leq 8.79$	4.5	7.29	.81
% Water	67	49.1	$47.24 \leq \mu \leq 51.11$	49.5	7.93	.96
% Weevil	80	11.6	$9.03 \leq \mu \leq 14.33$	8.0	11.90	1.33
% Pine needle scale	79	.34	$-.07 \leq \mu \leq .75$	0.0	1.84	.20
% Defoliator	80	3.7	$2.71 \leq \mu \leq 4.75$	2.0	4.58	.51
% Other pathology	80	11.9	$9.24 \leq \mu \leq 14.65$	8.0	12.13	1.35

APPENDIX VI
(cont.)

LOWER CROWN POSITIONS, YOUNGER TREES
1973 YEARS FOLIAGE

Parameter	N	$\bar{X}$	95% Confidence Interval	Median	σ	$s_{\bar{X}}$
ppm F	77	1.53	$1.36 \leq \mu \leq 1.70$	1.40	.74	.08
ppm S	77	490.00	$462.00 \leq \mu \leq 517.00$	500.00	121.00	13.80
% Needle retention	80	81.20	$77.70 \leq \mu \leq 84.70$	85.20	15.60	1.74
% Healthy needles	80	55.10	$50.10 \leq \mu \leq 60.10$	56.00	22.40	2.50
% Tip burn	80	4.90	$1.53 \leq \mu \leq 8.39$	0.00	15.40	1.72
% Basal necrosis	80	2.79	$2.00 \leq \mu \leq 3.40$	2.00	3.17	.35
% Basal scale	80	8.90	$6.20 \leq \mu \leq 11.70$	3.00	12.40	1.39
Needle length (mm)	80	122.50	$118.80 \leq \mu \leq 126.10$	121.70	16.50	1.85
Needle x sectional area (mm^2)	80	2.01	$1.89 \leq \mu \leq 2.12$	1.97	.50	.05
Total a+b chlorophyll	73	1.020	$.969 \leq \mu \leq 1.071$	1.019	.218	.025
% Mottled needles	80	6.2	$3.88 \leq \mu \leq 8.63$	1.0	10.66	1.19
% Needle necrosis	80	7.7	$5.69 \leq \mu \leq 9.79$	5.0	9.20	1.02
% Water	67	49.6	$48.78 \leq \mu \leq 50.43$	50.0	3.37	.41
% Weevil	80	12.4	$9.56 \leq \mu \leq 15.30$	8.0	12.88	1.44
% Pine needle scale	80	.81	$-.77 \leq \mu \leq 2.40$	0.0	7.15	.79
% Defoliator	80	4.0	$3.04 \leq \mu \leq 5.12$	3.0	4.67	.52
% Other pathology	80	8.3	$5.64 \leq \mu \leq 11.10$	4.0	12.28	1.37

APPENDIX VI
(cont.)

OLDER TREES, LOWER CROWN POSITIONS
1973 YEARS FOLIAGE

Parameter	N	$\bar{X}$	95% Confidence Interval	Median	σ	$s_{\bar{x}}$
ppm F	76	1.41	$1.25 \leq \mu \leq 1.58$	1.40	.71	.08
ppm S	76	492.00	$462.00 \leq \mu \leq 521.00$	500.00	128.00	14.60
% Needle retention	80	76.30	$72.30 \leq \mu \leq 80.20$	77.50	17.70	1.98
% Healthy needles	80	55.90	$51.40 \leq \mu \leq 60.40$	53.00	20.10	2.25
% Tip burn	80	2.30	$1.06 \leq \mu \leq 3.63$	0.00	5.70	.64
% Basal necrosis	80	2.60	$1.70 \leq \mu \leq 3.50$	1.50	4.00	.44
% Basal scale	80	8.30	$5.70 \leq \mu \leq 10.90$	4.00	11.70	1.31
Needle length (mm)	80	124.60	$120.30 \leq \mu \leq 128.90$	123.90	19.30	2.16
Needle x sectional area (mm^2)	80	2.15	$2.03 \leq \mu \leq 2.27$	2.15	.53	.05
Total a+b chlorophyll	77	1.021	$.976 \leq \mu \leq 1.066$	.999	.199	.022
% Mottled needles	80	6.3	$3.84 \leq \mu \leq 8.83$	1.00	11.22	1.25
% Needle necrosis	80	6.8	$5.25 \leq \mu \leq 8.52$	4.00	7.34	.82
% Water	67	48.4	$47.37 \leq \mu \leq 49.58$	48.5	4.53	.55
% Weevil	80	13.1	$10.03 \leq \mu \leq 16.21$	9.0	13.89	1.55
% Pine needle scale	80	.06	$-.002 \leq \mu \leq .12$	0.0	.29	.03
% Defoliator	80	4.9	$3.41 \leq \mu \leq 6.48$	2.5	6.88	.76
% Other pathology	80	9.6	$7.21 \leq \mu \leq 12.10$	6.0	10.97	1.22

APPENDIX VI
(cont.)

ALL CROWN POSITIONS, ALL TREE AGES
1973 YEARS FOLIAGE

Parameter	N	$\bar{X}$	95% Confidence Interval	Median	σ	$s_{\bar{x}}$
ppm F	307	1.44	$1.36 \leq \mu \leq 1.52$	1.40	.73	.04
ppm S	307	485.00	$471.00 \leq \mu \leq 499.00$	500.00	126.00	7.19
% Needle retention	320	83.60	$81.90 \leq \mu \leq 85.30$	88.40	15.22	.85
% Healthy needles	320	54.80	$52.30 \leq \mu \leq 57.20$	54.00	22.20	1.24
% Tip burn	319	3.54	$2.30 \leq \mu \leq 4.70$	0.00	10.90	.61
% Basal necrosis	320	2.50	$2.09 \leq \mu \leq 2.80$	2.00	3.20	.18
% Basal scale	320	8.60	$7.20 \leq \mu \leq 10.00$	3.00	12.60	.70
Needle length (mm)	320	128.30	$126.20 \leq \mu \leq 130.50$	128.20	19.50	1.09
Needle x sectional area (mm^2)	320	2.24	$2.16 \leq \mu \leq 2.31$	2.18	.64	.03
Total a+b chlorophyll	302	1.016	$.994 \leq \mu \leq 1.039$	1.010	.199	.011
% Mottled needles	320	7.5	$6.15 \leq \mu \leq 8.99$	1.0	12.91	.72
% Needle necrosis	320	7.5	$6.60 \leq \mu \leq 8.42$	5.0	8.24	.46
% Water	271	49.2	$48.59 \leq \mu \leq 49.85$	49.6	5.29	.32
% Weevil	320	11.9	$10.58 \leq \mu \leq 13.27$	8.0	12.21	.68
% Pine needle scale	319	.38	$-.04 \leq \mu \leq .81$	0.0	3.89	.21
% Defoliator	320	4.1	$3.57 \leq \mu \leq 4.73$	2.0	5.28	.29
% Other pathology	320	10.9	$9.55 \leq \mu \leq 12.44$	6.0	13.12	.73

APPENDIX VII

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

REPLY TO: 5200 Forest Insect and Disease Control June 28, 1976

SUBJECT: Insect Conditions at Colstrip

TO: Staff Director, Forest Environmental Protection

This memorandum documents observations made by Mark McGregor and Clint Carlson on the Colstrip study plots during August 3 to 8, 1975.

Purpose of the trip was to determine current status of insect species present, and potential for buildup.

Plots visited during the week were 1, 2, 6, 7, 9, 10, 12, and 13. It was not possible to visit all plots and from observations made, insects present were common to most of the plots.

The most prevalent insects seen were lady bird beetles, tentatively identified as Cleis sp., and Neomysia sp.; leaf-footed plant bug, Leptoglossus sp. These species are predacious, and were probably feeding on a myriad of foliage feeders such as aphids, scale insects, and mites.

In all plots, the elegans pine weevil, Scythropus elegans, was observed, and evidence of current needle damage as well as damage of past years was seen. However, this damage was classed as insignificant and is common to all Forests in the Region.

An unidentified mite was found feeding in the needle sheath at all plots. Significance of the feeding has not been determined. Several sawflies, Neodiprion sp., were found feeding on ponderosa pine at plot 12. Numbers of sawfly were so rare that no significant damage to ponderosa pine is anticipated during 1975 or 1976.

Pine loopers, Phaeoura mexicanaria, were found at plots 7 and 12, but pose no epidemic threat in the immediate future. A weakening of the stand may cause a population buildup of this species, which in turn could result in an outbreak of Ips calligraphus.

A weevil, Magdalis sp., was observed in several plots, but this insect has been observed to cause damage to new growth in reproduction areas following thinning, and was considered insignificant in areas examined at Colstrip plots.

Infestations of the mountain pine beetle, Dendroctonus ponderosae, and the pine engraver beetle, Ips pini, resulted from a blowdown that occurred during July at Yeager Butte, and thinning of second-growth ponderosa pine stands in the Three-Mile Creek area. These both have the potential for buildup to epidemic levels by 1976.

No other insects were observed that might have a potential for buildup to epidemic levens during 1975-76.

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